PRACTICAL METALLURGY *for* ENGINEERS

E. F. HOUGHTON & CO.

Newark, N. J.

PRACTICAL METALLURGY
for ENGINEERS

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BY THE
METALLURGICAL STAFF
OF
E. F. HOUGHTON & CO.

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FOREWORD

PERHAPS this book will be best appreciated if the reader is informed as to why it is published and how the information contained therein was obtained by the author.

The object of publishing "*Practical Metallurgy*" is solely for the purpose of contributing to the metal-working craft that knowledge of metallurgy which the Houghton Research Staff, because of its exceptional opportunities, has been able to compile in its years of research work.

Other works on this subject have been most creditable to their respective authors and very helpful to the industries, but such works have for the most part been the result of the personal knowledge and experience of one individual, and necessarily limited in their scope.

The college professor has written from the viewpoint of an instructor; the laboratory metallurgist from his experience, confined most likely to one or two laboratories, and the practical manufacturer has written from the scope to which a single individual engaged in the craft would naturally be limited.

The author of "*Practical Metallurgy*" is not a single individual, but a group of individuals organized for the purpose of ascertaining the best products—other than metal—used in practical metallurgy, as well as the best methods and processes by which such materials may be used in order to produce the best results.

While it is all very true that those engaged in the metallurgical craft have been fairly liberal in the contribution of their knowledge to the public by the reading

and publishing of papers on this subject, it is also true that there is a natural instinct on the part of those engaged in any craft to hold from their competitors certain information usually referred to as trade secrets.

When a member of the Houghton Research Staff seeks information in a large steel plant for instance, everyone connected with that plant will lend his hearty cooperation and be more than willing to trade experiences and knowledge with the Houghton Research Staff for two reasons:—

First: They feel certain they will receive more than they give.

Second: They are equally interested with the Houghton Research Staff in using best materials by best methods.

If there be a prominent metallurgical plant in any English speaking country to which a member of the Houghton Research Staff is not welcome, we are not aware of it, and as the Houghton Research Staff is represented in every metal-working district of the World, with the exception of Germany and Austria, the reader can appreciate that the author has had an exceptional opportunity for gathering and compiling knowledge.

But making knowledge a matter of record and being able to produce a comprehensive treatise on the subject, are two entirely distinct propositions.

Therefore, in the preparation of the copy for "*Practical Metallurgy*" the author sought to attach to their membership one who not only had a very wide personal experience and knowledge on the subject, but one who had the ability to prepare the basic copy for the book.

This basic copy once prepared, a procedure of additions, subtractions and amendments was begun by submitting the "copy" for the criticism of over a dozen men identified with the metallurgical craft in various capacities. Heads of public laboratories, college professors, practical manufacturers, those who have specialized upon one particular branch of the industry, such as casehardening or quench-

ing, etc., have all had their opportunity to criticise the "copy."

The author does not want it understood that such criticisms have always been accepted; the Chief of the Houghton Research Staff constituted himself as the final judge to pass upon the final copy, and where corrections and amendments of the original copy have been made as a result of criticism or have been over-ruled, it has been in accordance with the best judgment of the Chief of the Houghton Research Staff.

This is the fourth contribution which E. F. Houghton & Co. has made to the metallurgical craft, the other three efforts being the First, Second and Third editions of a book published under the title of "*Steel and Its Treatment.*"

In these former works, credit has been given to the individuals who aided the author in the compilation of "*Steel and Its Treatment,*" by giving the identity of each person who rendered such aid.

If these names are omitted in "*Practical Metallurgy,*" it is not to be considered as evidence that the author has had no such aid in the compilation of "*Practical Metallurgy,*" for as a matter of fact, the aid has been extensive and generous, but it is the desire of all concerned to avoid using this publication for the purpose of advertising either a product or an individual and these names have, therefore, been omitted at the request of those who have rendered such valuable aid.

In other words, "*Practical Metallurgy*" is a contribution, not an advertisement or an investment, and in order to avoid even a suspicion of commercialism, the author has subdued, as far as possible, all identity of individuals, the publisher being an artificial individual created by the State of Pennsylvania under the Incorporation Act.

CHAS. E. CARPENTER,
President of
E. F. Houghton & Co.

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INTRODUCTION

ENGINEERS, designers and machinists live in a world of metals, in which iron and steel play the greatest part. They use metals as their servants, and have an intimate knowledge of the virtues and vices of these materials, appreciating their various qualities as a man appreciates the qualities of his human associates.

A skilled executive will cause his ideas and schemes to be carried to success by men whose birth, education and early training are of small interest to him, and similarly the man who daily uses iron and steel or brass and aluminum is often ignorant or indifferent to the long and interesting story which tells the history of each bar of steel or each iron or brass casting with which he begins his work.

This history is alive with interest, and men of the drafting room and machine shop will not waste their time in reviewing the early life story of the material in which they are so deeply interested.

The following pages tell in a short and simple way the principles and practice followed in modern metallurgy. It will serve as an introduction to the study and learning of a host of practical details which a man must master who intends to make metallurgy his main calling, and will give a summary and outline of the previous history of the materials which the machinist and engineer use as a starting point.

"Metallurgy is the science and art of preparing metals for use from their ores by separating them from mechanical mixture and chemical combination," says Webster. The prospector and geologist may find the ore,

the miner will dig it out of the earth, and it will then be turned over to the metallurgist, who extracts the metal and works it into the condition in which the engineer and machinist desire it.

Although there is quite a large number of metallic elements, most of them are not directly used in mechanical engineering, and the following list covers practically all that merit attention from engineers and machinists.

USEFUL METALLIC ELEMENTS

Iron	Nickel
Copper	Antimony
Aluminum	Platinum
Zinc	Mercury
Tin	Silver
Lead	Gold

The foregoing elements are used in a more or less pure form, and to these must be added other metals, some comparatively rare, which are not used to any extent alone, but become extremely valuable when mixed or alloyed with other metals and particularly with steel. These are:

Manganese	Molybdenum
Chromium	Titanium
Vanadium	Tungsten

It is very difficult to obtain any of these metals in a state of absolute purity, and metals in the commercial form never are absolutely pure, and often contain up to 1% and more of impurities. Copper, lead, nickel and tin are to be obtained commercially in the purest state, but except for certain electrical purposes, and unusual and special instrument work, metals are not used, nor indeed required, in their pure state.

Metals are used because they have certain qualities desired by the designer, but it may be stated generally that few metals in the really pure state have the qualities which are desired when specified by the engineer. In practical work it is not the qualities of the metal in its pure state

that are usually wanted, but the qualities of the metal as modified by the presence in that metal of one or more other substances. Metals are never found naturally in a state of purity, and the metallurgist's chief problem, after receiving the ore, is to free the metal in that ore from its harmful associates, reduce the beneficial associates to the proper proportion and possibly add others. This is particularly the case with iron.

The art of metallurgy is largely the art of alloying, that is, the art of combining metallic and other elements to produce materials which have varying and desired qualities. Examine a number of specifications for machines of any kind and it will be found that a pure metal is scarcely ever asked for, and except for certain electrical purposes, as stated above, the qualities desired are not to be obtained from pure metals. The metallic materials used by engineers are chiefly alloys, and of these there is an endless variety.

The engineer and the metallurgist are very closely connected. On the one hand is the metallurgist who has produced material enabling the engineer to advance his designs, and on the other hand is the engineer who has instigated the metallurgist to improve the quality of his product and even turn out an entirely new material.

The art of metallurgy is very old. Prehistoric man knew how to produce a very good bronze, and there is reason to believe that iron and even steel were known and made in times as remote, but because of the rapidity with which iron and steel corrode and rust away it is not surprising that but few of the early iron implements remain to this day.

The metallurgist must work closely, not only with the engineer, designer and machinist, but also with the geologist, mining engineer, physicist, and particularly with the chemist—indeed, metallurgy might be considered as a branch of applied chemistry, and there are few professions more closely connected with the many varying branches of knowledge than metallurgy.

CHAPTER I

THE PHYSICS AND CHEMISTRY OF METALLURGY

Metallurgy is a science which deals with the properties of the metals and the processes by which they are obtained from their ores, and adapted for the use of man.

It is based on the laws of Physics and Chemistry which deal with the fundamentals of matter and energy and the changes which occur in matter.

In order to grasp clearly the subject of metallurgy it is necessary, therefore, that the fundamentals of Physics and Chemistry, which apply to metallurgy, be well understood.

First as to energy and matter:

Energy and Matter—*Energy* may be defined as the capacity for doing work, when by work is meant the act of producing a change of the state of matter against a resistance opposing that change.

Heat is one of the best known forms of energy. Its capacity for doing work is utilized in the steam engine, the gas engine, melting furnace, etc. The quantity of heat in a given piece is indicated by its temperature and the temperature in turn is measured by some form of thermometer.

In metallurgy, heat and temperature play a very important part, and it must be understood clearly that the temperature of a body indicates that condition which determines the transfer of heat to or from other bodies.

Temperature is measured by the expansion of a liquid such as mercury for low temperatures, and generally by means of a thermocouple for high temperatures.

Heat is measured in this country by the British Thermal

Unit, which unit is the amount of heat necessary to raise one pound of water at its maximum density one degree Fahrenheit.

Thus it can be seen that the heat contained in a body depends on the mass.

The unit of temperature of the Fahrenheit scale used in this country is obtained by dividing the expansion of a mercury column in a mercury thermometer between the freezing and boiling point of water by 180 and calling the freezing point 32°. On the centigrade scale, the freezing point of water is 0° and the boiling point 100°.

Matter is simply defined as that which occupies space. Matter is constantly undergoing changes. These are, 1st: physical changes, which do not affect the composition of matter, and 2nd: chemical changes which do affect its composition. The substances taking part in chemical changes are defined as chemical compounds or elements.

Chemical compounds are substances which are homogeneous throughout their masses and which cannot be separated by mechanical means. Chemical compounds are combinations of fundamental substances called "elements." Elements are those substances which have so far resisted all attempts at further dissociation. There are at the present time about ninety elements, each of which has been given a distinguishing name and symbol. By combining symbols a compound can be conveniently represented and reactions shown, thus:

$$2\ CO \text{ plus } O_2 \text{ equals } 2\ CO_2$$

meaning that two parts of carbon monoxide, composed of one atom of carbon and one atom of oxygen, will combine with one part of oxygen composed of two atoms of oxygen to form two parts by weight of carbon dioxide consisting of one atom of carbon and two of oxygen.

The elements have been given values based on the relative combining weight, using hydrogen as unity, which values are known as atomic weights and which permit the

calculations of the weights of reacting substances and the products formed. Thus from the table of atomic weights:

2 CO plus O_2 equals 2 CO_2

2 (12 plus 16) plus 2(16) equals 2 (12 plus 2(16)) equals 56 parts CO plus 32 parts oxygen equals 88 parts of CO_2.

Chemical reactions are of two kinds:

Exothermic, characterized by the evolution of heat and endothermic, by absorption of heat.

The most important reactions from a metallurgical viewpoint are Oxidation and Reduction.

Oxidation can be defined strictly as the combination of a substance with oxygen and *reduction* as the giving up of oxygen.

In metallurgy these two processes are of the utmost importance. When one thing is reduced another is oxidized, and an element in the metallic state is said to be reduced from its oxide.

Thus if iron oxide is acted upon by carbon when heated, the carbon reduces the iron oxide by taking away the oxygen of the iron oxide, leaving the iron. The iron oxide in giving up its oxygen is reduced to metallic iron, and conversely the carbon in combining with the oxygen of the iron oxide is oxidized to form carbon dioxide.

The chemical elements can be classified in two groups according as their normal compounds are acid or basic, and it is important in metallurgical processes that the acid and basic substances be clearly known. Acids and bases react to form new substances called "salts."

In order to prevent undesired reactions it is necessary in metallurgical processes that acid substances be used in contact with acid furnaces; that is, silica-lined furnaces, and that basic substances be used in conjunction with basic furnaces; *i. e.,* having magnesite or dolomite linings.

Table showing important elements according as they are basic forming or acid forming.

ACID-FORMING

Group	*Name*	*Symbol*	*Atomic Weight*
Chlorine	Fluorine	F	19.0
	Chlorine	Cl	34.46
	Bromine	Br	79.92
	Iodine	I	126.92
Sulphur	Sulphur	S	32.07
	Selenium (Rare)	Se	79.20
	Tellurium (Rare)	Te	127.50
Carbon	Carbon	C	12.00
	Silicon	Si	28.30
	Boron	B	11.00
	Titanium	Ti	48.10
Nitrogen	Nitrogen	N	14.01
	Phosphorus	P	31.04
	Arsenic	As	
	Antimony	Sb	120.20
	Bismuth	Bi	208.0
	Vanadium	V	51.0

CHARACTERISTIC ELEMENTS

Hydrogen	H	1.0 (1.008)
Oxygen	O	16.0 (15.97)

BASE-FORMING

Group	*Name*	*Symbol*	*Atomic Weight*
Potassium	Lithium	Li	6.94
	Potassium	K	39.10
	Sodium	Na	23.00
Calcium	Calcium	Ca	40.07
	Barium	Ba	137.37
	Glucinum	Gl	9.1
	Strontium	Sr	87.63
Magnesium	Magnesium	Mg	24.32
	Zinc	Zn	65.37
	Cadmium	Cd	112.40
Silver	Silver	Ag	107.88
	Copper	Cu	63.57
	Mercury	Hg	200.60
Aluminum	Aluminum	Al	27.1
	Gallium (Rare)	Ga	69.9
	Thallium "	Tl	204.0
	Scandium "	Sc	44.1
Lead	Lead	Ph	207.10
	Tin	Sn	119.0
Chromium	Chromium	Cr	52.0
	Molybdenum	Mc	96.0
	Tungsten	W	184.0
Manganese	Manganese	Mn	54.93
Iron	Iron	Fe	55.84
	Cobalt	Co	58.97
	Nickel	Ni	58.68

Occurrence and properties of some of the most important elements.

OXYGEN

Occurrence. This element is most widely distributed in nature, since 47.29% of the solid crust of the earth, 88.89% of water and 20.8% of air is oxygen. In air it exists in a free state, but in limestone, sand, marble, clay, quartz, iron ore, and many other substances it exists in a combined state.

Preparation. It is prepared by merely heating certain of its compounds, some of which are mercuric oxide, potassium chlorate and manganese dioxide.

Properties. Oxygen is a colorless, odorless, tasteless gas, heavier than air (sp.gr.s. 1.1056) and slightly soluble in water. At a low temperature and a high pressure it is converted into a liquid. Oxygen boils at —181° C.

The phenomenon of ordinary burning or combustion is due to the combination of oxygen with other substances. It unites with many elements to form a class of compounds, the oxides, and is necessary to life. Animals die in an atmosphere of less than 16% oxygen.

Some important oxides are carbon dioxide, CO_2; carbon monoxide, CO; calcium oxide, CaO; magnesium oxide, MgO; ferric oxide, Fe_2O_3; and ferrous-ferric oxide, Fe_3O_4. The last two are important as ores of iron.

HYDROGEN

Occurrence. Hydrogen does not occur in nature in a free state, but combined with oxygen it forms water, of which it constitutes 11.11%. In a combined state it occurs also in the bodies of plants and animals, hence, in the volatile matter of coal, in petroleum, and in natural gas it constitutes almost 25%. Water is one of the products of combustion when a fuel containing hydrogen is burned.

Preparation. It can be prepared by decomposing water by means of hot metal, hot coke, or the electric current,

and by treating certain metals with certain acids, or by treating aluminum with sodium or potassium hydroxide.

Properties. It is a colorless, tasteless, odorless gas, almost insoluble in water, and can be converted into a liquid that boils at —252°C. Hydrogen is the lightest substance known, being about 1/15 as heavy as air and 1/16 as heavy as oxygen. Its specific gravity, air standard, is .0696. It combines with oxygen in the proportion of 1 to 8 to form water. Its great tendency to combine with oxygen makes it an intense reducing agent.

SULPHUR

Occurrence. This element occurs free in the neighborhood of volcanoes and in underground deposits from which it may be prepared by purifying processes. In combined state it is found as FeS_2—$FeCuS_2$—PbS, the last two being valuable sources of copper and lead, respectively, as the sulphates $CaSO_4$, gypsum, $BaSO_4$, and $PbSO_4$; also in animal and vegetable matter. A little occurs in iron ore, coal and limestone, and when being reduced in the blast furnace it combines with the iron, and is very undesirable because of its injurious effects on steel and cast iron.

Properties. Sulphur is a brittle, yellow crystalline solid which melts at 114.5° C., forming a straw colored liquid. It is allotropic, *i. e.,* can exist in different physical forms. When heated to a sufficiently high temperature, it combines with oxygen to form sulphur dioxide, SO_2; with iron to form ferrous sulphide, FeS, and with most of the other metals to form sulphides. The sulphur in iron or steel is in the forms of FeS and MnS, distributed almost uniformly throughout the metal while in the molten state. Upon solidifying, however, owing to the difference in density and fusion temperature between these compounds and the metal, they may under normal conditions segregate to some extent, causing some parts of the solidified mass to

show a higher content of this impurity than the average of the whole in the molten state.

With hydrogen it forms a gas, hydrogen sulphide, H_2S, which is very important in chemistry, and has an odor of rotten eggs.

Uses. Sulphur is used in the manufacture of matches and black gunpowder, also for disinfecting purposes, for vulcanizing rubber and many other purposes.

Compounds. Besides compounds already mentioned, sulphur forms several acids, one of which, sulphuric acid, (H_2O+SO_3) (H_2SO_4), is a most important compound. It is obtained by oxidizing sulphur dioxide, SO_2, which is given off as a gas from the roasting of iron pyrites, FeS_2.

CARBON

Occurrence. This element occurs free in nature in crystalline forms as diamonds and graphite and in the amorphous form as coal. It is the chief constituent of the bodies of plants and animals, of all natural fuels and of most prepared fuels. It occurs in a combined state in limestone, magnesite, marble and other carbonate rocks.

Properties. Carbon is allotropic, diamond and graphite have been mentioned. The common amorphous forms are coal, lampblack, charcoal, coke, boneblack and gas carbon. Its density varies with its form.

Compounds and Uses. Carbon forms many compounds with hydrogen, called hydrocarbons, as methane, CH_4, ethylene, C_2H_4, benzene, C_6H_6, acetylene, C_2H_2, each one being but the first of a series of related compounds. With oxygen it forms carbon dioxide, CO_2, which is a product of combustion and of respiration. It is also given off when carbonates, such as limestone, are heated. The reaction is $CaCO_3 = CaO + CO_2$. Carbon monoxide is formed when the supply of oxygen is insufficient for the formation of CO_2.

Owing to its tendency to combine with oxygen to form CO_2, CO is a good reducing agent. So the CO formed before the tuyeres of the blast furnace reacts with the iron oxide thus:

$$3\ CO + Fe_2O_3 = 3\ CO_2 + 2\ Fe.$$

Carbon alone acts as a reducing agent in the metallurgy of iron:

$$3\ C + Fe_2O_3 = 2\ Fe + 3\ CO.$$

Iron forms carbides with carbon, the formula of one of which is Fe_3C.

In pig iron it is also found uncombined in the form of tiny flakes of graphite, hence the term graphitic carbon. Carbon has a marked effect upon iron. The varying properties of steel and the many uses to which it can be applied are due largely to the influence of this element. Carbon in steel then, up to a certain limit, is not to be considered as an impurity but as an essential ingredient.

SILICON

Occurrence. Next to oxygen, silicon is the most abundant element in nature. It is the most important constituent of the mineral part of the earth. Sea sand, quartz, jasper, opal and infusorial earths are composed of almost pure SiO_2. As silicates, it occurs in clay, mica, talc, hornblend and feldspar. On account of its wide distribution it forms the chief impurity of iron ore, as well as of all natural mineral deposits.

Compounds. As already indicated, silica, SiO_2, is one of the chief compounds of silicon. It also forms several acids, chief of which is silicic acid, $2H_2O + SiO_2$ (H_4SiO_4) which loses water when heated and forms SiO_2.

$$H_4SiO_4 = SiO_2 + 2H_2O.$$

Thus, in whatever form silicon may occur in an ore, it is looked upon as SiO_2. This substance is the great acid of dry chemistry, and at high temperature will neutralize any base with which it comes in contact. In the blast furnace

some silica (SiO_2) entering the furnace is reduced to silicon. The amount so reduced varies with the working conditions of the furnace, mainly the temperature. Once reduced, the silicon alloys with the iron and becomes a part of the metallic bath. All but a trace of this silicon is re-oxidized and removed in the various processes of making steel. However, a little is beneficial to steel, hence it is often added in small amounts in the form of an iron alloy.

NITROGEN

Occurrence and Properties. This element occurs to a limited extent in niter beds as salt peter, KNO_3, and Chili salt peter, $NaNO_3$, also in organic compounds and in coal. It is an odorless, tasteless, colorless gas and constitutes 78% of the atmosphere.

Compounds. With hydrogen it forms ammonia, NH_3, with oxygen a series of oxides, N_2O, NO, N_2O_5 and NO_2, and with hydrogen and oxygen, nitric acid, $H_2O + N_2O_5$ ($2\ HNO_3$). It is a very inert element and has slight effect in the manufacture of steel. Nevertheless, its presence in the air in such large amounts makes it an important factor in blast furnace operation.

PHOSPHORUS

Occurrence. Phosphorus, always combined with other elements, occurs widely distributed in limited amounts, particularly in soils. It is, therefore, found in all iron ores. It occurs in deposits as phosphorite and apatite, and is an important constituent of bones.

Properties and Compounds. While phosphorus belongs to the same group of elements as nitrogen, it does not much resemble it physically. It is allotropic and exists in two forms, as a pale yellow form that melts in boiling water and as a red form quite different in properties. While a much more active element it closely resembles nitrogen chemically. It forms analogous compounds with hydrogen and oxygen and an acid, $H_2O + P_2O_5$

($2\ HPO_3$), called metaphosphoric acid. Phosphorus is found in nature as salts of orthophosphoric acid, $3\ H_2O + P_2O_5$ ($2H_3PO_4$), and pyrophosphoric acid, $2H_2O + P_2O_5$ ($H_4P_2O_7$). It is reduced in the blast furnace. Reactions occur between the phosphorus compounds and the flux with the result that practically all the phosphorus in the raw materials is introduced into the resultant pig iron. In steel it is a very undesirable impurity, but fortunately it is oxidized readily, when it can be neutralized with lime and easily removed as a slag.

CALCIUM AND MAGNESIUM

While these two elements belong to different groups, they are very similar as far as the manufacture of iron and steel are concerned. With few exceptions one may be substituted for the other without inconvenience. They are the more important bases of dry chemistry.

Occurrence and Chief Compounds. Both elements occur as insoluble carbonates. Limestone, marble, chalk and marl are forms of calcium carbonate, $CaO + CO_2$ ($CaCO_3$). Magnesite is magnesium carbonate, $MgCO_3$. When heated, both these compounds decompose into the oxides and carbon dioxide, thus:

$$CaCO_3 = CaO + CO_2$$
$$MgCO_3 = MgO + CO_2$$

CaO represents quick lime and MgO magnesia.

These elements also occur together as a double salt of carbonic acid, calcium magnesium carbonate, $CaMg(CO_3)_2$, commonly called dolomite, which gives calcium magnesium oxide, CaO.MgO when calcined.

$$CaMg(CO_3)_2 = CaO.MgO + 2\ CO_2.$$

Uses of Lime and Magnesia. Lime, CaO, Magnesia, MgO, and the double oxide, CaO.MgO, are all very refractory. But on account of its tendency to "slack" in air, CaO is not used as such. Practically, MgO is the best basic refractory known, and calcined dolomite is the best available substitute.

The oxides are reduced with difficulty, and on account of their cheapness constitute the principal basic fluxes. As MgO is the leading basic refractory, CaO is the leading basic flux. It combines with both silica and phosphoric acid to form readily fusible slags, which have a lower density than iron and consequently lie upon the surface of the metallic bath.

ALUMINUM

Occurrence and Properties. This element in combined form is very widely distributed, occurring as one of the constituents of feldspar, granite, mica, cryolite and all clays. It is reduced from the oxide, Al_2O_3, by an electrolytic process, and in the metallic state it is applied to many uses. It has a strong affinity for oxygen, violently reducing iron oxide, and hence it is added to steel as a deoxidizing agent.

Compounds. In its compounds aluminum possesses decidedly basic properties forming salts with all the common acids except carbonic acid. It forms neither a carbonate nor a sulphide. Aluminum hydroxide, however, $Al(OH)_3$, acts both as an acid and a base. When this compound is heated it loses water and forms alumina, Al_2O_3. It is found in varying amounts in all the raw materials that enter into the metallurgy of iron. In the blast furnace it is never reduced. Its presence, however, has a marked influence on the slag, affecting its fluidity and fusion temperature, important considerations in blast furnace practice. In its pure state alumina is a good refractory, but its extensive use as such is prohibited by its scarcity.

CHROMIUM

Occurrence of this element is somewhat rare. In small deposits it is found as chromite, Cr_2O_3, FeO. This substance is the best neutral refractory known. In its pure state it melts at about 2175° C.

Properties and Uses. Chromium is both acid and basic in character. It is very important in the manufacture of

alloy or special steels. Its chief effect is one of hardening, hence it is employed to increase the hardness of projectiles, armor plate, automobile steel, and tool steels.

MANGANESE

Occurrence. This element occurs in nature as MnO_2, its deposits being somewhat limited in the United States. In very small amounts it is widely distributed, and is found in nearly all raw materials of iron manufacture. About 75% of this manganese is reduced in the blast furnace, so it is a constituent of all pig iron. But since it is readily oxidized in the purifying processes, except for slight traces, that found in steel is added intentionally. Its effect up to 1.0% is good, offsetting the evil effects of sulphur. Higher percentages, 7 to 15%, are employed to produce the special alloy known as Manganese Steel.

IRON

Occurrence. This most important metal occurs in combined states and, in slight amounts, in nearly all earthly matter, such as clays, soils, sands, etc. In deposits, it is found as the sulphide; as silicates; as a constituent of chromite; as the carbonate; and as the oxides, Fe_2O_3, and Fe_3O_4. The last named compound is magnetic.

Properties. Pure iron, almost unknown, is somewhat unlike the ordinary commercial forms. It is malleable and ductile, and magnetic. Its specific gravity is 7.78, and its melting point is higher than that of steel. The presence of carbon lowers the melting point rapidly.

Compounds. Iron forms two series of compounds, the ferrous and the ferric. The more important ferrous compounds are FeO, $Fe(OH)_2$, $FeCl_2$, $FeSO_4$; corresponding ferric compounds are Fe_2O_3, $Fe(OH)_3$, $FeCl_3$, $Fe_2(SO_4)_3$. Most of these compounds have a high commercial importance.

CHAPTER II

METALS AND THEIR ORES

There are many metallurgical processes which are carried out on metals after reduction. The whole series of alloys are made by the suitable mixture of various metals, and it is in the making of alloys that metals are desired in a purer condition than is required in cases where the metal is used alone, or in the degree of purity usual in commerce.

The most interesting and by far the most important alloys are the alloys of iron and carbon, which produce the numerous grades of cast iron and steel, and the alloys known by the names of brass, bronze, type metal, anti-friction metal, etc., are also of prime interest to the engineer. It is in the study of alloys, of their constitution, of their physical properties, and the changes that may be made in them by various treatments where metallurgy becomes difficult to understand, and the number and complications of terms used by writers on the subject often seem to have made the study more obscure than it really is. It must, however, be admitted that the scientific study of alloys is not yet old, and there are doubtless many enlightening discoveries yet to be made.

The physical properties of metals and alloys, rather than their actual composition, is after all the matter of greatest moment to the engineer or machinist, and these physical properties are imparted to metals and alloys largely by the treatment given subsequent to smelting or reduction. For example, in the long list of products which have the metal iron as the base, only a very limited number can be made directly from virgin cast iron as it comes from the blast furnace. All steel is made by conversion processes which must be carried out on cast iron subsequent to its production from the ore in blast furnaces.

Few articles of steel or cast iron can be made successfully without treatments subsequent to casting or conversion, and these treatments may consist of annealing, tempering or various operations known under the name of heat treatments.

The foregoing brief remarks explain a little of what the art of metallurgy consists, and in the following pages will be given short accounts of the methods of obtaining the commoner metals and the way in which they are treated and prepared for use by engineers and machinists.

In the appended table, a list of the commoner metals is given, the names and composition of the ores from which they are chiefly obtained, the usual method of smelting indicated, and a list of metals with which each is more commonly alloyed.

An ore of a metal is a natural substance containing one or more metals in such amount and in such form that the metal may be economically obtained from it. The earth consists of a number of different elements, some of which are more plentiful than others, some being metals. The elements are scattered around in innumerable combinations with each other. The earth's crust is made up of sedimentary and igneous rocks. The sedimentary rocks are formed by the wearing down of the igneous rocks and the deposition of the worn-off material on the bottom of bodies of water; the igneous rocks are those which have originally been in a molten state and probably represent the internal material of the earth. Geologists have calculated that 95% of the crust of the earth to a depth of ten miles is composed of igneous rocks. An average chemical analysis of igneous rocks shows the presence of all the previously mentioned metals, aluminum being present to almost 8%, iron to about 4½% and the others in small amounts down to less than one-hundredth of 1%.

METAL	SPECIFIC GRAVITY	MELTING POINT °C	RELATIVE ABUNDANCE % OF EARTH'S CRUST	VALUE PER LB. 1931 PENCE	ORES	COMPOSITION OF ORES	COUNTRIES WHERE FOUND	LIMITING TENOR OF ORES	METHOD OF SMELTING	ALLOYS WITH
ALUMINUM	2.56	658°	7%	9.26	BAUXITE CRYOLITE	ALUMINUM OXIGEN HYDROGEN ALUMINIUM SODIUM FLUORINE	U.S.A. FRANCE HUNGARY GUIANA GREENLAND	30%	ELECTRIC FURNACE	COPPER ZINC TIN GOLD
IRON	7.5 TO 8.1	1510°	4.7%	0.03 TO 0.04	MAGNETITE HEMATITE LIMONITE BOG ORE SIDERITE Carbonate	IRON OXYGEN IRON OXYGEN IRON OXYGEN HYDROGEN IRON CARBON OXYGEN	IN PRACTICALLY EVERY COUNTRY OF THE WORLD	25%	IN BLAST FURNACE WITH CORE, RARELY WITH COAL OR CHARCOAL OR IN ELECTRIC FURNACE	CARBON MANGANESE NICKEL CHROMIUM VANADIUM TUNGSTEN MOLYBDENUM TITANIUM COPPER
MANGANESE	8	1225°	LESS THAN 0.1%	0.02	PYROLUSITE PSILOMELANE	MANGANESE OXYGEN WITH MANY OTHER METALS	U.S.A. BRAZIL INDIA CUBA	30%	IN BLAST FURNACE WITH CORE	IRON NICKEL CHROMIUM
NICKEL	8.35 TO 9	1452°	0.01	0.41	GARNIERITE MAGNETIC PYRITES KUPFERNICKEL NICKEL GLANCE	NICKEL MAGNESIUM SILICON OXYGEN NICKEL NICKEL IRON SULPHUR NICKEL ARSENIC NICKEL ARSENIC SULPHUR	CANADA NEW CALEDONIA GERMANY AUSTRIA HUNGARY	2%	ROASTING SMELTING IN BLAST FURNACE REFINING	IRON COPPER ZINC TIN
COPPER	8.9	1083°	0.7	0.13	NATIVE COPPER OXIDES SULPHIDES ARSENATES UNDER MANY DIFFERENT NAMES	COPPER COPPER OXYGEN COPPER SULPHUR COPPER OXYGEN CARBON	U.S.A. SPAIN RUSSIA SIBERIA AFRICA AUSTRALIA GERMANY	1.3% IN SMELTING WORKS	OXIDES SMELTED IN BLAST FURNACE WITH CORE SULPHIDES ROASTED SMELTED IN BLAST FURNACE AND REFINED	TIN ZINC LEAD SILVER GOLD PHOSPHORUS IRON
ZINC SMELTER	7.1	419°	0.1	0.06	BLENDE Black Jack CALAMINE	ZINC SULPHUR ZINC OXYGEN CARBON	U.S.A. EUROPE	3%	CALCINED ROASTED AND DISTILLED WITH COAL CORE OR CHARCOAL	COPPER TIN ANTIMONY NICKEL GOLD
LEAD	11.3	327°	0.7	0.048	GALENA CERUSSITE	LEAD SULPHUR LEAD OXYGEN CARBON	U.S.A. SPAIN MEXICO AUSTRALIA	3%	ROASTING AND REDUCTION ON ORE HEARTHS OR IN BLAST FURNACES	ANTIMONY TIN COPPER
TIN	7.3	232°	0.4	0.34	CASSITERITE (TINSTONE)	TIN OXYGEN	MALAY PENINSULA BOLIVIA MEXICO ENGLAND	1%	SMELTING WITH CHARCOAL OR COKE IN REVERBATORY FURNACE	COPPER LEAD ANTIMONY BISMUTH CADMIUM SILVER
ANTIMONY	6.7	630°	0.1	0.09	STIBNITE	ANTIMONY SULPHUR	U.S.A. CHINA JAPAN FRANCE SPAIN	-	LIQUATION AT LOW TEMPERATURES REDUCTION WITH IRON OR ROASTING AND REDUCTION WITH CHARCOAL OR A VOLATILIZER	COPPER TIN LEAD
CHROMIUM	6.8	1365°	0.1	0.16	CHROMITE	CHROMIUM IRON	U.S.A. ASIA MINOR GREECE NEW CALEDONIA CANADA RUSSIA	30%	ELECTRIC FURNACE	IRON NICKEL
TUNGSTEN	18.1	1700°	0.1	0.53	WOLFRAMITE SCHEELITE	TUNGSTEN IRON MANGANESE TUNGSTEN CALCIUM OXYGEN	U.S.A. CANADA S. AMERICA	-	IN ELECTRIC FURNACE WITH CHARCOAL	IRON NICKEL CHROMIUM
MOLYBDENUM	8.6	2560°	0.1	2.00	MOLYBDENITE	MOLYBDENUM SULPHUR	U.S.A. CANADA NEWFOUNDLAND		ELECTRIC FURNACE	IRON
VANADIUM	3.3	1680°	0.1	5.00	VANADINITE ROSCOESITE PATRONITE CARNOTITE	VANADIUM LEAD OXYGEN CHLORINE	U.S.A. PERU	-	ELECTRIC FURNACE	IRON
TITANIUM	3.5	3000°	0.1	0.33	ILMENITE RUTILE	TITANIUM IRON OXYGEN	U.S.A. NORWAY AUSTRALIA	-	ELECTRIC FURNACE	IRON
PLATINUM	21.46	1780°	0.1	70.00 PER OZ.	NATIVE PLATINUM SPERRYLITE	PLATINUM ARSENIC	U.S.A. RUSSIA MEXICO	-	CONVERTED INTO THE CHLORIDE AND IGNITED	GOLD SILVER COPPER NICKEL TIN STEEL
MERCURY	13.59	-38.3°	0.1	0.67	CINNABAR CALOMEL	MERCURY SULPHUR MERCURY CHLORINE	U.S.A. SPAIN AUSTRIA SERVIA	-	ROASTING SUBLIMING	TIN COPPER ZINC SILVER GOLD AMALGAMS

By certain natural processes, many theories of which have been advanced, the metals which are scattered around in all rocks have a tendency to segregate together, and minerals are found in quantity containing large relative proportions of one metal. When this mineral contains enough of a metal to make the extraction of that metal from it a practical commercial proposition, then this mineral becomes an ore of that metal.

There are some metals which are found in the true metallic condition, known as native metal. This occurs most frequently with the precious metals, gold, silver and platinum, although copper, mercury and tin are also important in the native condition. It may be noted these metals are not easily subject to corrosion.

The common metals, however, occur economically as combinations of those metals with one or more of the following elements: sulphur, oxygen, hydrogen or carbon. These are called chemical combinations, and in chemical language ores are known as, sulphides when the metal is chemically combined with sulphur; as oxides when combined with oxygen; as hydrated oxides when combined with oxygen and also with water, which is itself a combination of hydrogen and oxygen; and as carbonates when combined with carbon and oxygen. If ores contained the metals in combination with these elements only, the proposition would be simple, but unfortunately there are always other elements present in greater or less amount. An ore often contains more than one metal, and when mined and prepared, even after elaborate cleaning and concentration, contains more or less material known as gangue, which is foreign matter coming from the rock or earth in which the ore deposits are found.

REDUCTION

The problem therefore is to break up this chemical combination and to get rid of the sulphur, oxygen, hydrogen, carbon and other foreign matters.

The agencies used are

1. Mechanical.
2. Chemical.
3. Application of heat, or regulation of temperatures.

In the use of mechanical treatment, ores are crushed to suitable sizes, or in some cases, where ores are very fine, are pressed or briquetted into lumps, and separated from foreign matter by the use of magnets, or by taking advantage of the different specific gravities of the ore and foreign matter.

The chemical treatment which is usually accompanied by the application of heat causes new combinations to take place, or splitting up the original combinations.

Every ore must be treated in a particular way, and the details and sequence of operations may differ widely, but the main principle in obtaining a metal from its ore is to bring it into contact with some other material or materials and raise its temperature, when the chemical combination of the ore will be split up, the union of the metal with the sulphur, oxygen or carbon will be broken, and sulphur, oxygen, etc., will unite with the added material and pass off. At the same time the gangue and other impurities will also unite with the added material, forming a slag, which has a different specific gravity and possibly a different melting point, and thus is capable of being separated from the metal, which is then obtainable in the molten and comparatively pure condition.

To carry out these operations fluxes and fuel are necessary. The oxygen of the air is also used. A flux is used chiefly to unite with the gangue, and make it more easy to melt. The fuel when burning, or to put it in chemical terms, when uniting with oxygen from the atmosphere, provides the heat necessary to cause the various chemical combinations to take place, as well as causing the physical change in the materials when they become fused or changed to the liquid molten condition.

The above statement of the process appears simple, but

many factors enter which complicate matters. High temperatures must be used, and consequently furnaces and hearths must be made of materials which will not melt. Moreover, the material used for making hearths and furnaces may have an influence on the chemical reactions in the furnace, and in the conversion of iron into steel the character of the furnace linings is of the utmost importance.

When a metal is free from the sulphur, oxygen, etc., with which it was combined, it is said to have been reduced, and the processes in which metals are obtained in a molten or fused state from the ore are called smelting processes.

CHAPTER III

FUELS

The high temperatures required in so many metallurgical operations are usually obtained by burning a fuel, with the aid of atmospheric oxygen. In certain cases the fuel not only provides the heat, but also enters into a chemical action which is actually part of the metallurgical process.

Carbon in various forms is the basis of practically all fuels. It has a very strong affinity for oxygen, thus it will readily burn, and is very plentiful in nature, occurring in coal, wood, petroleum and natural gas. There are special cases, however, where sulphide ores may act as their own fuel to a certain extent, utilizing the heat produced by the combination of the sulphur of the ore with oxygen. There are solid, liquid and gaseous fuels.

Coal is the most important of all fuels, and is used in the natural form as mined and also when prepared as coke. It is the basis from which producer gas, water gas and illuminating gas are produced. Coal is of vegetable origin and occurs in many varieties, which grade in character from lignite or brown coal (stated by geologists to be of comparatively recent origin) to bituminous, semi-bituminous and anthracite.

Coal in its natural condition is used in metallurgical operations for heating some types of furnaces. Anthracite can be used as a blast furnace fuel, but generally coal must be converted into coke in order to be suitable for most metallurgical operations. The reason for this is that coke is strong and porous, and will support a heavy load of ore and flux in the furnace and still leave air spaces so that oxygen from the blast can enter and promote combustion throughout the mass, whereas soft coal would pack down and crush to powder, and hard anthracite coal,

though possibly able to support the load at first, would quickly splinter and disintegrate when burning. In addition, coke contains no volatile constituents, and in burning produces a very hot reducing condition in the furnace without long and oxidizing flames, or tarry matter or smoke.

Good coke can be made only from certain coals known as "coking" coals, and the operation of coking is a sort of distillation, the coal being heated in ovens or retorts from which air is excluded. Coals act differently when subjected to this distillation, some (of the soft and bituminous variety) containing a large percentage of volatile constituents, give off much gas, while others (of the hard or anthracite variety) contain less volatile matter and give off little gas. When distilled some do not cake, but leave only a friable or powdery coke; others known as coking coals form a more or less strong, hard and porous coke.

Coke was formerly, and still is to a large extent, made in ovens (known as beehive ovens), in which some of the coal itself, together with all the gas produced, is burnt in order to provide the heat for coking. The modern method is to heat the coal in retort or by-product ovens. The retort is a long, narrow oven built of fire brick and having passages from the top for taking off the gas. Some of the gas is burnt around the outside of the oven, heating the whole oven to a high temperature. The coal in the oven is thus baked and made to give off its gas.

About fifty per cent of the gas made is required to heat the oven and the balance forms a valuable source of fuel for furnaces in the vicinity of the coke plant. The tar, ammonia, benzol, and other constituents of the gas are removed before the residual gas is burnt and hence this type of oven is called a by-product oven. In this form of oven coals of a naturally lower coking grade can be coked to a condition suitable for the blast furnace, which cannot be done in beehive ovens. Owing to the construction of the by-product oven, the coke formed is of short length and not as heavy as that obtained from the old beehive type oven. For this reason the beehive coke is pre-

ferred for some processes, such as in the foundry where the large size is an advantage in the cupola. Coke contains impurities which are detrimental in the furnace. The ash must be low and the sulphur content below a maximum amount for metallurgical purposes. In order to reduce the amount of ash and sulphur, coals are often washed before coking. A good coke will contain about 90% or more carbon, and not more than 0.75% of sulphur.

The coke remaining after coal has been distilled for illuminating gas is called gas coke, but it is not well adapted for metallurgical purposes, not being strong enough to support the furnace burden. A coke is also produced as the final residue in distilling petroleum, but this coke is close grained and not porous enough for furnace use.

Coke is used not only in iron smelting, but also in copper and other non-ferrous reduction work. It is also used as the fuel in cupolas for remelting, in crucible furnaces and for the production of water gas.

Charcoal is used now to a very limited extent only, although it has the excellent characteristics of being low in ash and containing no sulphur. Charcoal is strong enough to carry a moderate furnace load and can be used in small blast furnaces with success. Charcoal is made by the distillation of wood in a manner analogous to the making of coke, the distillation being carried out by burning piles of wood with a limited supply of air, or in kilns and retorts. Only hard woods produce charcoal of metallurgical value, and owing to the increasing scarcity of timber the cost of charcoal is becoming prohibitive except under rare and special circumstances. The use of raw wood as a fuel is negligible in metallurgical operations.

Oil is the only liquid fuel, and mineral oil is the only kind used. Mineral oils are composed chiefly of carbon and hydrogen, with small amounts of nitrogen and oxygen. In general, oil sold as fuel oil is crude oil after being "topped" or after having the gasoline and lighter oils removed. Oil is burned after being reduced to a fine spray, or atomized as it is called, by a jet of air or steam under pressure.

Oil has many advantages as a fuel for reverberatory furnaces and open hearths. It leaves no ash, can produce a very high temperature and permits of a very close control as to conditions of oxidization or reduction in the furnace; it can be handled by mechanical means with a minimum of labor.

In order to grasp clearly the characteristics and advantages of the different fuels, the simple fundamentals of combustion must be understood.

Since it is desired that the fuel in question combine with oxygen so that resultant heat may be made available, it is obvious that for efficient combustion, means must be provided so that each and every particle of the fuel be brought into contact with oxygen at the necessary temperature to start the reaction. Since the oxygen is obtained from the air and the air contains, in addition to the oxygen, approximately four parts of nitrogen for each part of oxygen, it becomes necessary also to heat this nitrogen to the flame temperature with resultant loss of available heat.

It can be readily seen that to permit of the easiest possible combustion the fuel should be in the gaseous state in order that the mixture of the fuel and the oxygen admitted for combustion be as intimate as possible.

Thus a fuel which is gaseous can be burned more efficiently than one which must of necessity be gasified either in the furnace or in specially built gas producers.

In the case of coal, the fuel must be heated initially to a temperature of about 1400° F., at which it will give off gases which ignite and burn.

With coal the oxygen in the presence of the excess carbon burns the carbon to form carbon monoxide gas, which in turn reacts with the oxygen of the blast or draft to burn to carbon dioxide, both reactions giving off available heat.

In the case of oil, the liquid is converted in a suitable burner to vapor or mist of finely divided liquid surrounded

by the air from the blast. This vapor becomes immediately heated and gasified, combining with the available oxygen to complete combustion. The vapor consists generally of hydrocarbons which, unless they combine with oxygen, are heated to incandescence and are visible as a flame. If they are cooled down below the combining temperature before they meet any oxygen, they become black and are visible as smoke. Therefore, smoke is an indication of incomplete combustion, while flame is an indication of incandescent hydrocarbons which may or may not find available oxygen for combustion.

These points are characteristic of all burner operations and should be borne in mind by the furnace operator.

It is also evident that in order to insure complete combustion of fuel oil in the ordinary furnace excess air must be mixed with the oil in order to have oxygen available for each minute globule of vaporized oil.

The gaseous fuels are natural gas, coal gas, producer gas and water gas. Natural gas is an excellent and easily controlled fuel, but its increasing scarcity is curtailing its use.

Natural gas is chiefly composed of marsh gas, which is a compound of carbon and hydrogen, together with free hydrogen, oxygen and small quantities of other organic gases. It may vary in composition according to the locality where it is found. Its heating value is greater than that of coal gas, producer or water gas.

Coal gas, produced by distilling coal, is not used as a metallurgical fuel to any great extent, except in smaller heat treating furnaces.

Producer gas, which is very largely used in open hearth and steel mill regenerative furnaces, can be made from low grade coals, coke or even lignite, although the sulphur content for the open hearth furnace is generally held below one (1%). It is made by passing a limited amount of air and steam through a bed of incandescent coal or coke in a gas producer. The coal is stirred at regular intervals

to break up holes in the fuel bed and insure that the coal bed be consumed uniformly. The air admitted is sufficient to produce the heat required to maintain the fuel bed temperature. The steam furnishes hydrogen and oxygen, which combine with the carbon of the coal, according to the following equation:

$$C + H_2O = CO + H_2$$

The CO and the H_2 are both combustible gases, but since air is admitted the resultant producer gas is diluted by nitrogen with corresponding decrease in the unit heating value. A cubic foot of producer gas contains generally about 130-140 B.T.U.'s.

Water gas is made by blowing steam through a bed of incandescent coke, the gas being formed as in the equation given above. No nitrogen is present, however, since the producer is brought to the proper working temperature by blowing air through the hot carbon and venting the products of combustion to the air. These products are the CO_2 and nitrogen which dilute the producer gas. In order that the producer may be blown at regular intervals, two or more producers are used so that there will always be one or more producers making gas while the others are being blown. Water gas contains about 300 B.T.U. per cubic foot, and is being extensively pushed as an ideal fuel for general metallurgical processes.

Gaseous fuels are very suitable for all metallurgical operations, except in the blast furnace. They are clean, ashless and readily controlled, and except for small amounts of sulphur contained in many producer gases, do not introduce any harmful impurity into the metal being heated.

CHAPTER IV

REFRACTORIES

Most metallurgical operations require the employment of comparatively high temperatures, and therefore furnaces and containers of all kinds for hot metals must be made of material which will not melt, or be destroyed at the temperatures required, and also must be of a nature which will not affect the metal with which it comes in contact to an important degree. Suitable materials are known under the general name of refractories, and it is evident that they must be able to withstand very hard usage. A good refractory, therefore, must not alter its chemical or physical condition at the temperatures to which it may be subjected. It must be inert to chemical reaction with any other material with which it may come in contact. It must be strong and hard enough to resist wear and leakage, also it must have a low expansion and contraction coefficient and be low in radiating power and conductivity.

The most plentiful refractory material probably is sand, which is used largely for making moulds into which hot metal may be cast, and in making the hearths of acid open hearth furnaces. Sand consists of oxide of silicon, or silica, in small grains, and should not contain more than a small percentage of other material as impurities. The presence of lime or metallic oxides tends to make sand more fusible. Sand, being chiefly silica, is of an acid nature, and therefore is not suitable in furnaces where high phosphorus pig iron is to be converted into steel, since phosphorus can be eliminated only by means of a slag of lime or equally basic material.

The next most plentiful refractory material, and the most largely used is fire clay, which is a mixture of silica and oxide of aluminum, or alumina, and also usually con-

tains lime, metallic oxides and other impurities. The silica of fire clay may cause it to be acid in character, although fire clay is often considered to be neutral. Although generally inert at common furnace temperatures, as regards most metals, in the case of steel at high temperatures there is dissociation of the oxygen and silicon due to the carbon in the steel, and metallic silicon joins with the steel. The acid character of fire clay, due to its silica content, prevents its use in steel conversion furnaces where it is required to reduce phosphorus, and the production of a basic slag would cause reaction between the fire clay and the slag, which would quickly destroy the fire clay. Fire clay is used generally in the form of bricks or crucibles which are molded from the plastic clay and then burnt. Many grades of bricks are made from fire clay with varying mixtures of sand and loam.

Silica brick, made of crushed quartzite and lime, is acid in character and is used largely for the roofs of reverberatory furnaces. Silica brick has a high fusing point, but is not very strong.

Carbon in the form of graphite and plumbago is used for making crucibles and sometimes for lining furnaces. Carbon will withstand a very high temperature, and will produce a slightly reducing condition. Some metals, however, such as iron, nickel and others, will absorb carbon at high temperatures, and therefore carbonaceous crucibles cannot always be used.

Lime, which is oxide of calcium, and which is made by calcining limestone, is used for lining the bottom of basic converters. It is generally mixed with tar and rammed into position when in a plastic mixture. Lime is basic in character.

Magnesia, which is also basic, is similarly made by calcining a natural carbonate of magnesium called magnesite. It is used in the form of bricks, but as magnesite does not occur in this country to a great extent and is very expensive, a refractory having very similar characteristics is made from dolomite, which is a carbonate of

magnesium and calcium, and which is calcined in the same way as limestone. There are a number of patented bricks and refractory linings made from different mixtures of magnesia or dolomite. Basic converters and basic open hearth furnaces are usually lined with dolomite in some form.

Chromite, or chrome iron ore, is a natural mineral consisting of iron and chromium oxides. It is made into bricks and used in basic open hearth furnaces. It is neutral in character.

There are many other refractory materials sold under trade names and made from mixtures of various silicon, aluminum or carbon compounds. These, however, are generally for laboratory work. In industrial practices it may be roughly stated that blast furnaces are lined with bricks made of fire clay and silica, and converters and open hearths are lined with silica bricks and sand when the process is acid, and dolomite or magnesite when the process is basic; crucibles are made of fire clay or graphite.

CHAPTER V

TEMPERATURE MEASUREMENT

Almost every plant doing any form of heat treatment is equipped with pyrometers. Many, however, lose all the advantages which come from the possession of such an equipment by the failure to understand the nature of the instrument and to keep watch over its condition.

In the heat treatment of steel too great an emphasis cannot be laid upon the controlling and regulating of the temperature of heating, whether it be for hardening, drawing or annealing. In the treatment of steels where the critical changes must be determined and the furnace regulated to the predetermined heat we are forced to depend on the pyrometer.

In the heat treatment of steel the types of pyrometers most generally used are the thermo-electric and the optical. Of these two the thermo-electric method is by far the more important.

The theory on which the operation of thermo-electric pyrometers is based can be briefly described as follows:

If, when two wires of different composition are joined together at both ends so as to make a complete circuit, and one of these junctions is at a different temperature from the other, a difference of electrical potential is set up at the junctions and an electric current flows through the wires. Such a pair of wires is called a thermo-electric couple. If the wires are of uniform composition the potential difference depends upon the difference of temperature alone, and the strength of the current will vary directly as the differences of temperature. If a galvanometer or a millivoltmeter is inserted in the circuit, this current can be measured, and if the current corresponding to various differences of temperature is once ascertained, the apparatus can be used as a means of measuring tempera-

ture. The thermo-electric couples are divided into two principal classes: Base Metal and Noble Metal couples.

There appears to be an insistent demand on the part of many in charge of technical processes requiring temperature control for inexpensive and robust measuring apparatus. For this reason, if for no other, the use of the base metal couple has become firmly established, and its success lies principally in the production of fairly satisfactory alloys having considerable changes of electromotive force with small temperature changes, which can be made into strong, practically unbreakable, thermocouples, and the development of an inexpensive fairly robust millivoltmeter.

Practically all the base metal thermocouples in commercial use at present are made of one of the following combinations: Iron-(copper-nickel); (nickel-chrome)-(nickel-aluminum); or (nickel-copper)-(nickel-chrome).

The former are more efficient when used in furnaces in a reducing atmosphere. The latter are more desirable in an oxidizing atmosphere.

The standard noble metal couple is made of platinum, and an alloy of platinum with 10% of rhodium.

The thermo-electric force of these various base metal couples is quite constant and is in the majority of cases unaffected by furnace gases. Sometimes, however, the materials of the couple may be altered in a uniform manner by the heat and minor errors introduced. Further, the heat of the furnace is almost sure to cause the materials to disintegrate, thus reducing the cross section of the couple and increasing its resistance. This increase in resistance allows less current to flow for a given electromotive force and is the source of serious errors.

The platinum-platinum 10% rhodium thermocouple has been partly superseded by the base metal couples on most work where absolute accuracy is not essential. The former couple, however, is used solely for checking and standard work.

The service a pyrometer is called upon to furnish is very severe. The thermocouple is always subjected to

high temperatures, under the influence of which even the best materials sooner or later deteriorate; the measuring instrument in a very considerable number of cases must be mounted where there is considerable dust, dirt and heat, and these are almost certain to affect the moving parts, which are necessarily delicate because of the small amount of power generated by the thermocouple. A pyrometer must be examined at frequent intervals if it is not to become a source of trouble and loss.

A good checking equipment is a valuable addition to any pyrometer system, but there are various ways in which the man who does not have checking apparatus may ascertain whether his pyrometer is in reasonably good condition.

To ascertain whether the service couple is in good condition, keep on hand two or three spare thermocouples, and put at least two couples in the furnace with their tips close to the tip of the service couple. When the extra couples have been in the furnace long enough to reach the temperature of the old couple, as indicated by the fact that all three are the same color, read the service pyrometer, disconnect the leads from the service couple and connect them to one of the other two, making sure that polarities are right. Read the pyrometer again. If the two readings agree, the service couple is in good condition. If they do not agree, connect to the third couple, which will then demonstrate conclusively the correctness of the service couple.

To check the wiring at a time when the furnace or oven is heated and holding a fairly constant temperature, take a reading on the pyrometer; disconnect the meter from the leads and take the meter directly to the terminals of the thermocouple; connect and take another reading; and make a note of the difference in the two readings for future reference. It is well to do this with a new couple. The difference between the reading as permanently installed and as directly connected meter to couple will be constant as long as the wiring is in good condition.

The indicating galvanometer reading is checked up against a potentiometer reading.

Failure to properly handle the "cold end" of the thermocouple is a common source of inaccuracy in pyrometer equipment. The cold end of the couple is the point at which the thermocouple joins other materials, such as copper lead wire or brass terminals. The reading of the pyrometer, unless it fortunately is one of the new automatically compensated types, varies as the temperature between the hot end and the cold end varies. The operator should not accept any reading from his pyrometer until he has satisfied himself that the cold end temperature has been either compensated for automatically or otherwise, or has been stabilized and allowed for.

The millivoltmeter should be checked at least once every three months, but this must be done by someone possessing a potentiometer or other standardizing equipment.

OPTICAL PYROMETERS

Where it is inconvenient, or impossible to apply a thermocouple to an object in order to determine the temperature, optical pryrometers are sometimes used, and are of much assistance in gaging the temperature of molten metal in casting, pieces in the rolling mill or forgings under the hammer or press. In this type of instrument, which can be made in portable shape, the relation between the light waves given off and the temperature of a hot body is utilized. There are several types of optical pyrometers in which by proper arrangement the color or brightness of the object whose temperature it is desired to measure, is compared with a standard lamp, the difference being interpreted in degrees of temperature. In the instruments which are probably most commonly used, in place of a standard lamp, an electrically heated filament is compared with the hot object and by a suitable resistance, the current causing the filament to glow is regulated until the brightness of the filament corresponds to the brightness of the hot object. The electric current then corresponds to a scale of temperatures in degrees F. or C., and thus the temperature of the hot object can be closely approximated.

CHAPTER VI

MISCELLANEOUS METALS

ZINC

The most important ore of zinc is Blende, which is zinc and sulphur, or zinc sulphide. Another less important ore is Calamine, which is a combination of zinc, carbon and oxygen, or a zinc carbonate. There are also other ores of small commercial importance.

The first process in smelting is to convert the sulphide or carbonate ore into an oxide, which is done by roasting the sulphide in the air, replacing the sulphur of the ore with the oxygen of the air, and by calcining the carbonate ore, when the carbon is driven off in the form of carbon dioxide. The zinc oxide then is mixed with a considerable amount of coal, charcoal or coke, and is heated to a high temperature in retorts made of fire clay. At the high temperature the carbon combines with the oxygen of the zinc oxide, and since an excess of coal, coke or charcoal is present, the carbon passes away as carbon monoxide. At the high temperature, however, the zinc volatilizes or distills off and cannot be obtained directly in the molten condition in the retort. The zinc vapor passes into clay condensers and condenses partly to molten zinc and partly to zinc fume, which is a fine powder composed of zinc and zinc oxide. The molten zinc is collected from the condensers and cast into slabs. This is the crude zinc or spelter of commerce, and contains lead and iron as impurities.

Zinc can be refined by what is known as a liquation process. When impure zinc is kept molten at a temperature just a little above its melting point, comparatively pure zinc will separate from the lead and iron which sink to the bottom of the vessel, the lead and iron being alloyed

with a small portion of zinc. Electrolytic methods are also being used at the present time in zinc production.

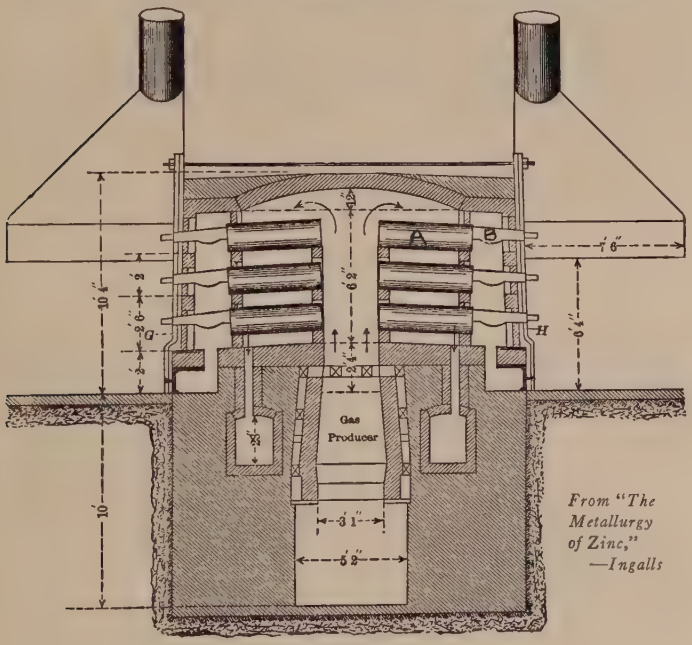


FIG. I
ZINC SMELTING FURNACE
(A)—Retort. (B)—Condenser

Zinc is a bluish white metal with a very crystalline fracture. It can be rolled into sheets and drawn into wire only at a temperature between 100° and 150° C. as at other temperatures it is brittle. It distills and will burn in the air at a comparatively low temperature. Like copper it does not corrode in dry air, but in moist atmospheres a thin skin of zinc carbonate forms on its surface, after which no further corrosion takes place. This prop-

erty makes it of great value as a protective coating for iron when used in galvanizing.

The zinc alloys are very important. With copper it forms the numerous brasses, and enters also into some bronzes; zinc and aluminum alloys are used for light castings, and many anti-friction metals are composed chiefly of zinc with tin, copper, antimony or lead.

Zinc has the property of precipitating certain metals when they are in solution. Thus zinc is used to precipitate gold in the cyanide process of gold extraction.

ANTIMONY

Stibnite, which is antimony and sulphur, and senarmontite are the only important ores of antimony, the former being the most common.

The first process in smelting stibnite is "liquating," which is really a form of concentrating the ore. In liquation the ore is heated just enough to melt the antimony sulphide, but not the gangue. The liquated sulphide of antimony is known and sold as crude antimony. The liquation may be done in several ways, either in pots with perforated bottoms, in tubes or in reverberatory furnaces, but the principle in each is the same.

The liquated sulphide is reduced to the metallic state by heating it with scrap iron, the iron combines with the sulphur, leaving metallic antimony and iron sulphide as a slag. The process is repeated to get rid of the iron, and finally the antimony is refined.

A method of treating less pure ores consists in roasting at a fairly high temperature; antimony oxide is produced which volatilizes and is collected in bags. The antimony oxides then are reduced in a reverberatory furnace with carbon and fluxes.

Antimony is a bluish white metal, not affected by the atmosphere at ordinary temperatures. It is very brittle and cannot be worked or hammered.

Commercial antimony usually contains over 99½% of pure antimony, the impurities being arsenic, iron and other metals in small amounts.

Antimony is used only in alloys, its properties when in pure state being of small value. Antimony is an important alloying metal, although it is very seldom employed as the predominating metal in any alloy. The most important alloys containing antimony are the anti-friction metals and type metals.

Antimony has a harmful influence as an impurity in copper when used for brass, causing the brass to crack when rolled. Antimony will harden lead and is used in lead bullets. Type metal in which the antimony content does not exceed 15% has the property of expanding when cooling after being cast, and hence will give well-defined castings. There are also many alloys of antimony and tin which are used for household metal ware.

MERCURY

Mercury is found native as an amalgam with other metals, or combined with sulphur in the ore Cinnabar. Mercury is extracted from the ore by distillation. The ore, sometimes mixed with fuel, is heated in a furnace and the gases are conducted through iron pipes lined with cement, and as the gases cool, mercury is deposited. Mercury is refined by redistilling and can be cleaned from foreign matter by filtering.

Mercury is in the molten condition at ordinary atmospheric temperatures. At 39°C. it solidifies to a white, malleable and ductile metal. Mercury does not corrode in moist air and has considerable acid resisting qualities. Commercial mercury is over 99% pure, and may contain very small amounts of zinc and lead. The alloys of mercury are called amalgams, and have many industrial uses.

Mercury will not alloy with iron, aluminum, platinum or manganese.

PLATINUM

Platinum is found in the native condition. It is commonly alloyed with other rare metals. The usual method of obtaining the platinum free from the gangue material is to heat the ore with aqua regia, which is a mixture of nitric and hydrochloric acids. The platinum is dissolved and ammonium chloride is added to the solution. Platinum forms a combination with ammonia and chlorine, and is precipitated as a very fine yellow powder. This is dried and heated to a high temperature, when the ammonia and chlorine are driven off, leaving metallic platinum.

Platinum is grayish white, and is not acted on by moist air nor by single acids. It is very ductile and malleable and can be beaten or rolled into very thin sheets. Its melting temperature is very high. Platinum alloys with many metals, and the alloys with copper and silver are of industrial use. With some of the rarer elements platinum alloys are used as wires in thermocouples.

VANADIUM

As in the case of previous metals, vanadium is used only as an alloy. It is obtained as a ferro-vanadium alloy from the ores Vanadinite, Patronite, Carnotite and Roscoetite, by reduction in the electric furnace.

The ores are oxide ores and the reduction is accomplished with carbon, molten iron being added to make the ferro alloy and also to prevent oxidization of the vanadium. The vanadium content of the commercial ferro alloy varies, and it is sold according to the amount of vanadium present.

Ferro-vanadium can also be obtained from the ore by the thermit process with use of aluminum.

Vanadium is said to be a light gray metal, hard, brittle, and devoid of malleability, but it has seldom been reduced to the pure metallic state. The vanadium steel alloys are used largely for automobile work, when the percentage of

vanadium varies between about 0.10% to 0.25%, and for tool steels where the vanadium content is about 0.5% to 1.00%. Vanadium steels are resistant to fatigue stresses and are valuable for this property.

MOLYBDENUM

In the eighteenth century molybdenum was first extracted from the sulphide MoS_2, called molybdenite, which occurs in nature and is practically the only commercial source of supply for this metal. The sulphur is removed by reduction in the electric furnace, and the product for use in steel is the alloy of iron and molybdenum, ferromolybdenum. This alloy has its lowest melting point when the content of molybdenum is approximately 55%. Phosphorus and other impurities are retained in the final alloy, so particular care is necessary in the selection of the ore.

In the pure state molybdenum is a soft and ductile metal with a very high melting point. It is worked into sheet and wire for use in heat resistors and apparatus that must withstand extraordinary temperatures.

Molybdenum came into prominence during the year 1918 as a result of the shortage of other steel alloying elements and from the tonnage placed in service and beneficial properties shown now has a proven field among alloy steels.

Before the year 1918, molybdenum was considered a rare metal. The sudden demand developed several notable deposits in the United States which were opened up on a large scale, so that at the present time molybdenum is the only one of the steel alloying elements found in this country in quantities sufficient to supply all domestic needs and leave a balance for export.

Molybdenum increases the desirable properties in steel. It is added in fractional percentages with the average content less than 0.50%. The physical characteristics of the steel after heat treatment increase noticeably with the addition of molybdenum up to 1.00%, but this element has a

pronounced effect in amounts less than 0.25%. A number of standard types of molybdenum steel have been developed for commercial use, including combinations with other alloys. These offer maximum combinations of strength and hardness on the one hand, with ductility or toughness on the other, and also at reduced cost for finished parts, because of the ease with which molybdenum steels are heat treated, forged and machined.

The quality of easy machineability is especially pronounced in molybdenum steels. Experience based on large tonnages in quantity production has shown a remarkable increase not only in production but in the life of cutting tools. This quality means that parts which must be heat treated and machined afterwards can be utilized in a state showing higher physical properties than customarily have been obtainable.

Molybdenum steel undoubtedly has a great future before it, promises to become one of the most useful alloy steels and has an unusually broad field of application. Its advantages are recognized by large consumers who have adopted the steel as a distinct improvement over other alloy steels where the consideration of strength, toughness and economy are of prime importance. Molybdenum steel appears to be especially suited to automobile and other structural requirements. Doubtless further improvements will be made and higher qualities obtained in such steels.

TUNGSTEN

Tungsten, like manganese and chromium, is rarely extracted from its ores as a pure metal, but is obtained as a ferro alloy and used in making alloy steels. There are two tungsten ores, Wolframite, which is tungsten, iron and manganese, and Scheelite, which is tungsten and calcium.

The reduction can be carried out in an electric furnace with carbon. Ferro-tungsten contains from about 60% to 85% of tungsten.

The metal itself has little commercial importance. It is light gray in color, hard and brittle, and has a very high melting point. Except for use in making filaments for electric lamps, tungsten is used only as an alloy with steel. Tungsten chromium steels have a peculiarity which gives them great value as tool steels. When heated to a high temperature and cooled quickly they attain a hardness which will remain even when the steel is again brought to a red heat. Tools made from such steels will continue to keep their edge when working so heavily that they are heated to dull redness. It is from this outstanding feature that this type of steel derives its name of "High Speed Steel."

In these steels the tungsten content will vary between 5% and 25%, chromium between 2% and 10% and carbon 0.25% to 1.00%. The common high speed steel now in use will analyze chromium 2% to 4%, and tungsten 14% to 18%.

Steels also containing certain proportions of tungsten and chromium have the power of retaining magnetism, and because of this outstanding property are used for making permanent magnets.

CHROMIUM

Chromium is obtained from Chrome Iron Ore, or Chromite, which is a mixed oxide of chromium and iron. The metal is not of commercial importance, and is chiefly required as an alloy for steel making.

Ferro-chrome, as the iron alloy is called, is obtained by reducing the ore with powdered coal in an electric furnace. It usually contains from 60% to 80% of chromium, and a considerable amount of carbon. The carbon content can be reduced by a process of refining in the electric furnace. Low carbon ferro-chrome is known as mild ferro-chrome. A purer form can be obtained by reduction with aluminum by the thermit process.

Chromium is a hard gray metal having a high melting

point. It does not oxidize easily, and ordinary acids have little action on it. Its chief use is as an alloy in steel, generally being in the proportion of about 1 to 2%. It is also frequently used with nickel, and with vanadium, producing nickel-chrome and chrome-vanadium steels. Its effect on steel is to give great hardness, and it is used in making projectiles. It appears to have the power of imparting hardness to great depth in large sections, giving what is called penetration hardness. The patented "stainless steel" contains from 10% to 15% of chromium.

The presence of a 2.00% to 4.00% of chromium appears to be necessary in the so-called high speed steels, which are mentioned under tungsten.

Chromium steels are used for making magnets.

LEAD

There are two classes of lead ores, sulphide ores and ores consisting of combinations of lead, carbon and oxygen. The most important ore is Galena which is a sulphide of lead. Galena always contains silver, usually in amounts which make its extraction a commercial proposition. Often it contains also iron, copper, zinc and gold.

Cerussite is another lead ore, being a lead carbonate, that is, lead combined with carbon and oxygen. Cerussite is not mined now so much as formerly, and galena is the ore from which most lead is now obtained.

Lead smelting in Europe and elsewhere is usually carried out in a reverberatory furnace; the lead sulphide becomes oxidized, and reacts with the sulphide and metallic lead is obtained. In this country lead is smelted almost entirely in blast furnaces. Coke is used as a fuel, and certain fluxes are sometimes added to form a more fusible slag. It is usual also to roast the sulphide ores first, thus converting part of the sulphides into oxides. During the smelting some lead is converted into fume which escapes from the top of the furnace; and to save this loss the

gases from the furnace are conducted into long flues where they cool and the lead is deposited.

Since lead ores nearly always contain silver, the lead obtained from the blast furnace is called base bullion, and must be refined separately to recover the valuable silver content. A matte is also obtained from the lead blast furnace which contains iron sulphide, lead sulphide and all the copper which may have been in the ore in addition to a certain proportion of silver and gold, if any were present. This matte is roasted and melted to recover the valuable metals.

The most interesting refining process of the base bullion is the desilvering; there are several methods of doing this. In the Pattison process, use is made of the fact that certain alloys of lead and silver have a lower melting point than pure lead. The base bullion is melted in an open kettle and allowed to cool. When the temperature has fallen to the point where pure lead melts, crystals of pure lead begin to form in the kettle. The crystals are scooped up in a perforated ladle, allowed to drain from the molten alloy and then placed in another kettle which is kept hot, and in which the crystals again melt. The process is continued in a similar way, crystals being transferred to other kettles until a lead of sufficient purity is obtained in one kettle, and a silver lead alloy of sufficient richness in another. There are modifications of this process in which steam is blown on to the surface of the melted metal.

In the Parkes process use is made of the fact that lead and zinc do not make a true alloy, and when melted together they will keep separate from each other, also that silver will alloy with zinc much more readily than with lead, and if lead containing silver is melted with zinc and the molten bath stirred up, the silver will be held by the zinc and can thus be removed from the lead when the two metals separate. The separation takes place when the molten bath is allowed to stand, the zinc rises and forms a crust on the surface of the lead and can be skimmed

off with perforated ladles. The silver zinc is then heated in a retort, where the zinc distills off and leaves the silver. The zinc fumes are collected in a condenser and the zinc recovered.

Lead has a white, bright color when freshly cut, but quickly turns to a dull gray color in the air. It is the softest of the more common metals and can be scratched with the fingernail. It oxidizes very slightly in moisture, and resists the action of dilute hydrochloric and sulphuric acids. It is very malleable and ductile and can be rolled or hammered into thin sheets. It is one of the heavier metals.

Impurities, especially antimony, increase the hardness of lead, and commercial lead is sold as soft and hard lead, the latter containing antimony. Other impurities are copper, silver, zinc and iron, but the commercial metal usually contains over 99% of pure lead.

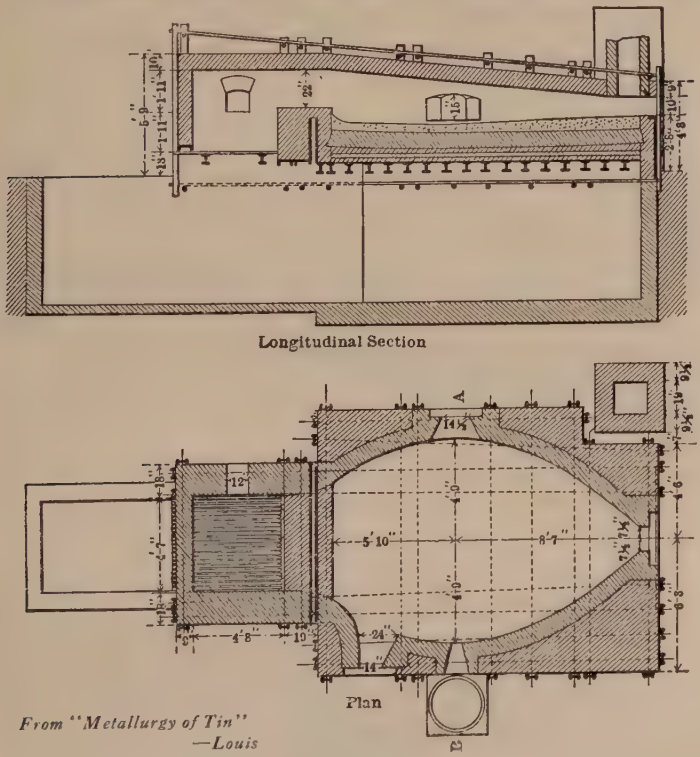
Lead alloys with many other metals, and in combination with tin, antimony, and sometimes copper it is the basis of pewters, type metals, anti-friction metals, plumber's solders, etc.

TIN

There is only one ore of tin which is commercially important. It is known as Cassiterite, and is a combination of tin and oxygen. This ore is commonly associated with sulphides of iron, copper, arsenic and frequently with tungsten.

Tin ore is generally concentrated before any smelting operation is attempted, various mechanical methods of concentrating being employed. After concentration the ore, which is mixed with sulphides of other metals as impurities, is roasted, and the sulphides are converted into oxides. The ore, which now consists of a mixture of oxides, frequently is concentrated again, by which means a large part of the iron oxide is removed. Copper and bismuth oxides, if present, are removed by treating the ore with dilute acids, which dissolve certain oxides, but which have no action on the cassiterite or tin oxide.

The tin smelting is carried out in furnaces which differ in different localities; where the ore can be obtained in a very pure state, small blast furnaces are used, and for less pure ores a form of reverberatory furnace is adopted. The prinicple in smelting tin is to mix the oxide with carbonaceous material, usually ground coal, and heat the mixture to a high temperature. The tin oxide is reduced to metallic tin by carbon monoxide. A difficulty in smelting tin is caused by some of the metal combining with the slag.



From "Metallurgy of Tin"
—Louis

FIG. 2
TIN SMELTING FURNACE

After the pure metallic tin has been run from the furnace, the slag also is cast into moulds and smelted again.

Most commercial tins are over 99% pure tin, the impurities consisting of antimony, arsenic, lead, copper, bismuth iron, silver and sulphur.

Tin is a brilliant white metal with a yellowish tinge. It is soft, malleable and ductile, and can be hammered into very thin sheets. Tin has a peculiarity which is observed at very low temperatures, as its structure then changes and it disintegrates to a powder.

Tin does not corrode in wet or dry atmospheres and is therefore very useful as a protective coating for iron and steel.

Tin alloys with a large number of other metals. The bronzes and gun metals are important alloys of tin and copper. Pewter is tin alloyed with about 20% of lead; tin alloyed with antimony, copper and sometimes lead, in varying proportions, is the basis of a number of anti-friction or bearing metals. The chief virtue of such anti-friction metals lies in their structure, which consists of small crystals of considerable hardness which resist wear, but which are embedded and joined together by a soft and plastic matrix, thus the wear-resisting particles adapt themselves to the rubbing surface and form an even smooth bearing.

COPPER

There are several copper ores, and the metal is found also in the native condition. In the latter condition copper occurs as small particles disseminated through certain rocks. Near Lake Superior there are enormous deposits of rock containing native metallic copper.

The two important ores are Chalcopyrite, which is a combination of copper, iron and sulphur and sometimes is called copper pyrites, and Chalcocite, which is also a combination of copper and sulphur and at times iron. There are many other ores which are combinations of copper and sulphur or copper and oxygen, and some of these are

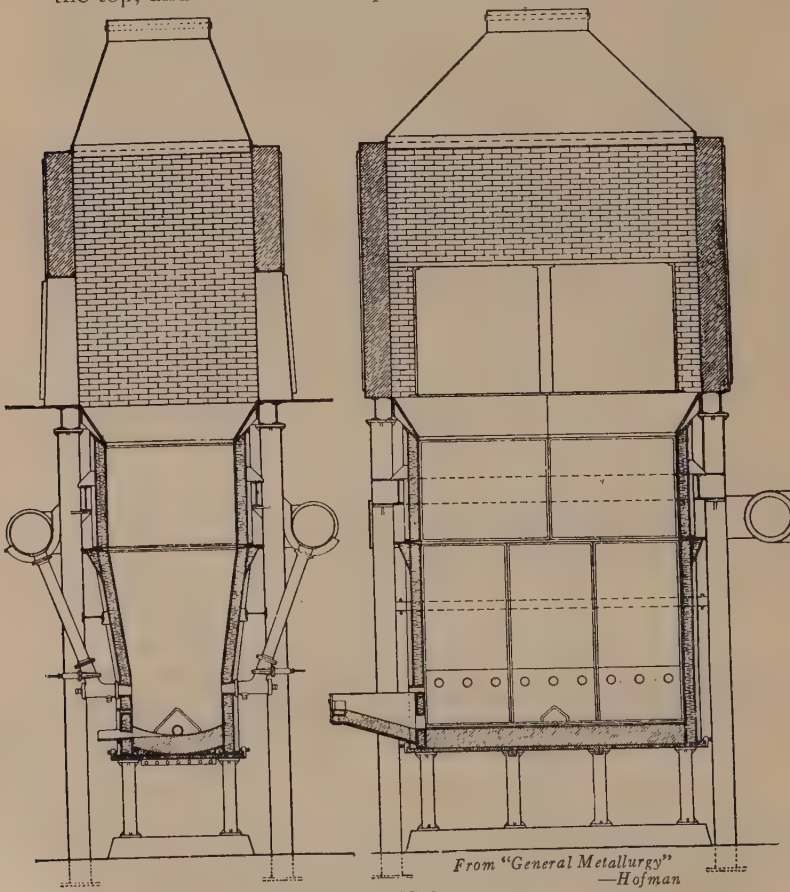
important, but the chief supply of copper is obtained from the two first-mentioned ores and the native metal.

The extraction of copper from its ores is a complex process entailing a number of operations, and no method whereby it may be done in one operation has proven successful. Much work is done in concentrating copper ores before the actual reduction processes are started, and there are few metallurgical methods which have not been applied to the production of copper.

Where copper oxide ores are available, the smelting is comparatively simple. The ore is mixed with coke in a blast furnace and air blown in, when the oxygen of the ore combines with the carbon of the coke leaving metallic copper, which is cast into ingots ready for refining.

Most of the ores, however, are sulphides and need to be treated differently. The ore as it comes from the mines consists of metallic sulphides and gangue or earthy matter, which is largely a combination of silicon and oxygen. If this ore mixture is fused, the sulphide portion is heavier than the earthy portion, which forms a slag that can be removed. The earthy matter or matter largely composed of silica is difficult to melt and it requires the addition of a flux in order to obtain fusion without an excessively high temperature. Such a flux might be provided by using lime, but a method is adopted by which the ore is partly converted into a material which will act as its own flux. This is accomplished by roasting the ore while it is being freely supplied with air. The ore contains iron sulphide as well as copper sulphide, and when iron sulphide is raised to a certain temperature in the presence of the oxygen of the air the chemical union between the iron and sulphur breaks, the iron joins with oxygen, becoming iron oxide, and also the sulphur joins with oxygen becoming sulphur dioxide and passes away. After roasting, therefore, the ore becomes a mixture of copper sulphide, iron oxide and the earthy matter. The iron oxide is a flux for this earthy matter and when the ore is raised to a high temperature in the blast furnace or

reverberatory furnace it is entirely melted, the copper sulphide sinking to the bottom of the slag, which now contains the iron as well as the earthy matter floating on the top, and it is then a simple matter to separate the two.



From "General Metallurgy" —Hofman

FIG. 3
COPPER MATTING FURNACE

The copper sulphide resulting from this operation is called "Matte." It must, of course, be understood that all the iron sulphide is not converted into oxide. It is impossible in many metallurgical operations which are carried on upon a large scale that every reaction should take place as thoroughly as is feasible in an experimental way in a chemical laboratory. The iron sulphide that remains mixes with the copper sulphide and comes out in the matte.

In addition to this iron sulphide, the matte will contain the other metals besides copper and iron which were present in the ore. There is practically always a number of other metals in small quantities present; silver, gold, antimony, arsenic and others being common.

In the next operation the copper is separated from the sulphur; this is done in a reverberatory furnace or in a Bessemer converter. The principle on which the convertor works was discovered many years ago by Bessemer and applied by him to the conversion of pig iron into steel, and was afterwards adapted to the needs of copper smelters. The principle is that when air is blown through certain materials when in a heated and molten condition, the oxygen in the blast will unite with or oxidize the elements of which the molten material is composed in a certain sequence, and thus the impurities or substances which it is required to remove are converted into gases which pass off, or into slags which can be removed before the metal itself is oxidized, and by stopping at the right time the metal is left comparatively pure. The most important feature of the principle, however, and the feature which makes it practicable is that the oxidizing reaction gives out heat, maintaining the material under treatment in a molten condition.

The converter for copper smelting is generally a barrel shaped vessel provided with holes in the side through which a heavy blast of air is blown. The vessel is swung about its axis and is capable of being tilted at any angle. It is lined with a refractory or not easily

melted material, the character of which has an important bearing on the process.

The melted copper matte from the blast furnace is poured into the converter and the blast of air turned on. The iron sulphide in the matte is converted by the oxygen from the blast into iron oxide and sulphur dioxide, which latter is a gas and passes away. The iron oxide unites with the silica of the converter lining (if the converter is silica lined, or as it is called, acid lined), making a slag which finally is poured off. After the iron has been oxidized, the sulphur of the copper sulphide is oxidized, also passing away as a gas, and the process is stopped, leaving fairly pure copper which is cast into molds.

The above is a very brief and rough statement of what occurs in a copper converter, but without going into long details it may be indicated that other impurities are also oxidized and removed, that the addition of ores containing a gangue of silica will help to supply the iron oxide with silica in order to make a slag, and that some of the copper itself becomes oxidized. It will be noted that the lining of the converter, when made of silica (known as an acid lining) enters into the making of the slag and therefore is quickly eaten away. To avoid this, converters are now lined with a material of the nature of lime, or what is known as basic material, which will not unite with iron oxide (which is itself a base), and the necessary silicon is supplied from silica-bearing ores.

Copper ores nearly always contain small amounts of gold and silver, and it is found that if a certain proportion of a matte is converted into copper all the gold and silver contained in that matte is carried in that copper. Taking advantage of this, the silver and gold are concentrated and finally separated.

Copper from the converter is still only crude copper, and must be refined, since it contains sulphur and other impurities.

The copper from the converter is remelted on the hearth of a reverberatory furnace and air freely admitted; the remaining impurities are oxidized and float on the surface and are skimmed off. In order to eliminate as much of the impurities as possible, the oxidizing is carried on until the copper itself begins to oxidize. The final process is to remove this oxygen from the copper. This is done by "poling" or thrusting green wood into the molten copper. The gases produced by the wood deoxidize the copper, and the refined copper is cast in molds for the market.

At the present day a great deal of copper is refined electrolytically. The crude copper is cast into anode plates, which are suspended in a bath of copper sulphate, and by passing a heavy electric current through the plate and sulphate, copper is dissolved from the anode plate, and is deposited on another plate. This deposited copper is very pure.

Commercial copper is over 98.7% pure copper. The impurities are lead, arsenic, sulphur, iron and nickel.

Copper is one of the most useful of metals. It is very malleable and ductile, and can be rolled into very thin sheets. It does not corrode in dry air, but becomes coated with a thin film of green carbonate of copper in moist atmospheres. Copper has greater electrical conductivity than any other metal except silver. It also is an excellent conductor of heat.

Copper is the basis of all the important alloys known as the brasses or bronzes. The brasses are alloys with zinc, different proportions giving brasses known as "best yellow" Muntz metal, Naval brass, etc. The bronzes are alloys with tin, and are known under such names as gun metal, bell metal, etc. There are special alloys or bronzes made by additions of phosphorus, aluminum, manganese, nickel, etc., each possessing special qualities, which adapt them for different purposes.

German silver is a copper, zinc, nickel alloy, and there are several alloys adapted for bearing metals which consist of copper, with tin, zinc, lead and other metals.

ALUMINUM

Aluminum is obtained from an ore, Bauxite, which is a mixture of aluminum and oxygen and iron and oxygen. These are hydrated oxides, and therefore also contain hydrogen. There is another ore of aluminum, Cryolite, which is a combination of aluminum with sodium and fluorine, but aluminum is actually obtained from Bauxite, although Cryolite is used in the process.

Aluminum is very abundant in nature, occurring practically everywhere in many combinations with other elements, but it is only recently that methods have been perfected to produce the metal commercially, and this has been due to the development of the electric furnace.

The first operation in the production of aluminum is to obtain a pure oxide of aluminum from the Bauxite. The oxide of aluminum is known as alumina. The Bauxite is crushed and heated in revolving steel roasters in order to destroy any organic matter, but chiefly to drive off the water which is present in chemical combination. The heated, or as it is called, calcined, material is then ground to a fine powder and heated with a solution of caustic soda in closed vessels under pressure. The resultant liquor is filtered and from it there settles out aluminum hydrate, a combination of aluminum, oxygen and hydrogen. The iron and other impurities of the original Bauxite are thus eliminated. The aluminum hydrate is again calcined and converted into a comparatively pure alumina, when it is ready for the electric furnace.

Another method of refining the calcined Bauxite is to heat it with a small amount of carbon in a bauxite and carbon lined electric furnace, where the iron, silicon and other impurities are largely reduced to metallic condition, leaving a refined alumina.

The electric furnace in which the actual reduction of alumina is accomplished consists of a pot lined with carbon, in which cryolite is kept in a molten condition. Cryolite is a combination of aluminum, sodium and fluorine,

and it is used to form a bath in which the previously prepared alumina can be dissolved. A heavy current of electricity is passed through the melt from a carbon rod inserted into the bath, the other electrical connection being made to the carbon lining of the pot. When the electric current passes through the melt, the oxygen which was combined with the aluminum unites with carbon from the carbon rod, and metallic aluminum segregates to the bottom and can be run off and cast into molds. The process can be continuous; alumina is added from time to time, and as the carbon rod is used up it is replaced.

Aluminum is a white and comparatively soft metal. Commercial aluminum contains over 99% of the pure metal, and the more common impurities are iron and silicon. Pure aluminum will not corrode in the atmosphere, but the presence of impurities cause it to become slightly corrodable.

It is the lightest of all metals commonly used in industry, and its value in engineering is largely based on this quality of lightness. It is malleable and ductile (being the most malleable metal after gold, silver and copper), and since its electric conductivity is comparatively high, it is valuable when drawn into wire for long distance electric transmission.

Aluminum has considerable deoxidizing properties when melted with other metals, and it is used as a deoxidizer in steel casting. The Thermit welding process depends on the great heat produced by the oxidation of aluminum when it reduces iron oxide.

Aluminum forms a number of alloys with various metals, some of which are of commercial importance, being light and malleable and capable of attaining a certain degree of hardness. Aluminum, however, forms definite chemical compounds with a number of metals, and these compounds are liable to form crystals united by an aluminum matrix, a structure which is not satisfactory.

Alloys of aluminum and copper give the series of alumi-

num bronzes, in which the composition may be from 4% copper and 96% aluminum up to 11% aluminum and 89% copper. Such bronzes work well when hot, but must be annealed frequently.

Alloys of aluminum and zinc are very often used, those containing about 20% of zinc having useful properties. Aluminum and magnesium alloys are also used, one containing about 3.50% to 5.50% of copper, about 0.50% of manganese and some magnesium, silicon and iron known as Duralumin, and is capable of being hardened by heat treatment.

MANGANESE

Manganese is usually found in ores associated with iron as oxides. The commonest ore is Pyrolusite, although manganese is present in a large number of other ores. The extraction of pure manganese from its ores is very difficult, and since manganese as a metal is practically useless, the pure metal is not obtained commercially. The important use of manganese is as an alloy with iron, and therefore both the iron and manganese are reduced together from the ore as ferro-manganese. Manganese-iron alloys containing less than about 30% of manganese are called Spiegeleisen, and those containing over 30% of manganese are called Ferro-manganese. The reduction may be carried out in blast furnaces with coke in a manner practically similar to the production of pig iron. The ferro-manganese so produced is high in carbon, and cannot be used in the production of some metals. At the present day ferro-manganese which has a low carbon content is produced in electric furnaces and also by reduction with aluminum, as in the thermit process.

Manganese is a light gray metal, very hard and brittle. It is not malleable and cannot be forged. As stated above, it is of commercial importance only when alloyed with other metals. It alloys with many metals; with copper manganese produces the so-called manganese bronzes, con-

taining about .10% of manganese, but the most important manganese alloys are with iron and steel.

Manganese is, after carbon, the most important ingredient in steel, and has great influence in deoxidizing and desulphurizing. The usual manganese content of steel is from 0.30% to 1.00%. Above this amount it renders steel brittle, but between 12% and 15% manganese content, it imparts hardness and toughness to steel, and alloys of this kind are largely used under the name of manganese steel. Manganese has an important influence on cast iron; its presence has an effect on its hardness, and makes machining more difficult; it is believed to assist the absorption of carbon by the iron, and has an influence in preventing the formation of graphite. In steels the effect of manganese is interesting. The so-called Hadfield steel, containing about 10% to 15% of manganese is a very tough, ductile steel. Manganese forms a combination with carbon called a carbide, like iron, and in manganese steels and irons this manganese carbide is associated with the cementite or iron carbide.

Low carbon steels with less than 5% manganese have a pearlitic structure, between 5% and 12% a martensite structure and about 12% an austenitic structure. The introduction of manganese into steel slightly increases the tensile strength during the pearlitic stage, but increases as the martensitic stage is reached. These steels are hard and brittle and of no practical use.

As the austenitic stage is reached this alloy loses its brittle character and becomes exceedingly tough.

NICKEL

Nickel is obtained chiefly from an ore called Garnierite, which is a combination of nickel, magnesium, silicon and oxygen and hydrogen, and from magnetic pyrites, which is a combination of nickel, iron, copper and sulphur. The presence of copper complicates the operation of obtaining pure nickel, and today a natural alloy of nickel and copper is sold and used under the name of Monel metal.

The sulphide nickel ore is roasted and the sulphur largely eliminated as sulphur dioxide, but some sulphur remains. The roasted ore is then smelted in a furnace and a matte consisting of nickel and iron sulphides obtained, although a greater part of the iron combines with silicon and oxygen in the furnace and is removed as a slag. The matte is then melted in a reverberatory furnace and air blown on the molten surface. The remaining iron sulphide is converted into a slag with the silica of the furnace lining.

This process is sometimes carried on in a Bessemer converter, as done in copper extraction. The nickel sulphide, however, cannot be reduced to metallic nickel, but remains as a pure sulphide. The pure sulphide or matte is then roasted, which converts the sulphide to oxide, and the resultant nickel oxide is reduced with the charcoal. This process is sometimes assisted by mixing first the oxide with flour and water and cutting up the resultant cakes into small cubes, which are then heated with the charcoal.

Nickel is extracted from its ore by another process, known as the Mond process, which depends on the property that nickel possesses of combining with carbon monoxide gas, producing a gaseous compound, nickel carbonyl, and this again decomposes into pure nickel and carbon monoxide when heated to temperatures between 50° and 150° C. The matte from the converter is crushed and roasted, producing nickel oxide; the copper impurity is then dissolved out with acids. The nickel oxide is then treated with carbon monoxide obtained from water gas, and the nickel carbonyl decomposed by heat, the nickel being deposited in a granular form.

Nickel is a white metal, almost as bright as silver. It is malleable and ductile and can be welded. Very thin sheets and fine wire can be made from it when pure, but impurities decrease its ductility.

Nickel does not corrode quickly in moist air, and is used as a protective on other metals.

Commercial nickel is often impure, containing not more than 98% of pure metal. The product of the Mond process, however, is purer. Its common impurities are cobalt, copper, iron, carbon and silicon, and these impurities greatly affect its properties. Commercial nickel is sold as ingots, electrolytic and "shot nickel." A special malleable nickel for stampings is also prepared.

There are many nickel alloys, probably the most important being the nickel steel alloys which are used largely in ordnance. In steel making the nickel is introduced in the form of pig or shot. There are also chrome-nickel, tungsten nickel and molybdenum nickel steels, in which the two metals may run in varying proportions.

Monel metal, mentioned above, is an alloy of nickel and copper, with small amounts of iron, manganese and silicon, which is made directly from the copper nickel ores.

An interesting alloy of steel with about 36% nickel has a very low coefficient of expansion and is largely used under the name of Invar metal. Nickel is also used in alloys designed for base metal pyrometers or thermocouples, and an alloy containing about 45% nickel and 55% copper is sold under the name of Constantan for this purpose. Nichrome, containing from 60% to 80% nickel with chromium and iron, is used for resistance wires. Cupro-nickel, containing 15% nickel and about 85% copper, is used for bullet jackets. The nickel silver used so largely in household plate has the following composition:

52% to 80% copper
10% to 35% zinc
5% to 30% nickel.

The ignition points of many spark plugs are made of a manganese nickel alloy containing 2% to 4% of manganese and the remainder nickel.

CHAPTER VII

IRON ORES

Iron is used to a greater extent than any other metal, and its metallurgy is of the highest interest. Iron is the second most plentiful metal on earth, and is found in all corners of the world.

The ores of iron are oxides, sulphides and carbonates; that is, iron combined with oxygen, sulphur or carbon and oxygen. Anxiety has been expressed by some writers that the supply of iron ore is being depleted at too rapid a rate, and certainly the known deposits of the richest ores have been greatly reduced by the enormous yearly tonnage which has been mined, but the known deposits of less rich ores are very great, and it is stated by geologists that as ores descend in the scale of richness in iron, the greater they are in abundance, and that there is little doubt but that ores for the practical production of iron for all needs will be available for many generations.

The reason why iron has become the most useful material known to man lies in the property which iron possesses of uniting with carbon and forming combinations which can be made to acquire a range of physical properties of a very wide extent.

Pure iron is of little practical use as such, but in association in different ways with varying amounts of carbon it is converted into numerous varieties of wrought iron, steels and cast irons, forming the raw stock so much needed in the work of the engineer and machinist.

Before giving a more detailed account of the processes followed in producing iron and steel, the main operations will be outlined. The ore is smelted in blast furnaces. The magnitude of this operation is so great that the question of the supply of fuel becomes as important as the

supply of ore, and in the consideration of the economic value of a deposit of iron ore, as much regard must be paid to the proximity of coal fields as to any other feature.

The blast furnace produces pig iron, which is the starting point from which cast iron, steel and wrought iron are made by remelting or conversion processes. When cast iron is required, the pig is remelted in cupola furnaces and cast into the required shape. The large variety of steels are made from pig iron by the regulation of the carbon content in crucible furnaces, Bessemer converters, open hearth or electric furnaces, there being a number of varieties of each, while wrought iron is made from pig iron in puddling furnaces.

All irons and steels, after being obtained of the right composition, require mechanical or other treatment to impart the right physical properties, and the history of a piece of steel from the ore to the machine shop is long and complicated.

The ores of iron from which the great majority of iron is produced in this country are combinations of iron and oxygen, known as oxide ores or hydrated oxide ores. There are other iron ores, an important ore in England being iron combined with carbon and oxygen, an iron carbonate, and known as clay ironstone. There are also large deposits of sulphide ores, which is iron combined with sulphur; these, however, are not mined primarily for the iron they contain, but are used for the production of sulphuric acid.

American ores are Magnetite, Hematite and Limonite. Magnetite is the richest iron ore. It is an oxide of iron containing 75% of iron and is magnetic, a property which is made use of in concentration. The best deposits of magnetite are fast becoming depleted.

Hematite is mined to a much greater extent than any other ore in America. It is also an oxide of iron, and contains about 70% metallic iron.

Limonite, or what is sometimes called brown ore, is an

oxide of iron, containing water, and hence is called a hydrated oxide. This contains about 59% of metallic iron. The above percentage of iron content refers, of course to the pure mineral, and the ore as it comes from the mine is mixed with more or less foreign material or gangue. If an ore was obtainable composed of the pure mineral only, smelting would be very much more simple.

It has been remarked that the available supply of fuel is of prime importance in considering the value of iron ore deposits. An examination of the reports of the production of ores from the various ore fields show at once that iron ore is mined in quantity only in places comparatively near to coal fields, and where coke or the necessary fuel for smelting may be obtained. There are, roughly, three belts of iron ores in the United States of America: one in the east, extending from New York State to Alabama; one about the west and south of Lake Superior, and another, somewhat scattered through the western States. Only the Lake Superior and eastern belts are worked to any great extent at the present day, and it will be noted that these regions in general are not far from the main coal fields of the country. The Lake Superior ores are the furthest from coal, but the Great Lakes form a natural waterway and afford cheap transportation. The deposits of ore in the western States are too far from coal to make their development economically profitable at present, but doubtless they will be mined in the near future.

A word may be said about fuel. Coke is used almost entirely in blast furnaces, and a suitable coke for blast furnace use cannot be made from every kind of coal. There are different classes of soft or bituminous coals. Some cake together when heated in coke ovens and some do not; while others, although caking and thereby producing a coke, do not give the kind that can be used for metallurgical purposes. A blast furnace coke must be strong and porous; it must not crush under a heavy load of ore and flux, and must not contain too much ash. It is very important that a coke should not contain more than a certain amount of

sulphur, because in the blast furnace the sulphur affects the iron. Coke is, at best, a friable material and will not bear a great deal of handling without breaking into pieces too small for blast furnace use, hence it is often more advisable to transport ore to the coke rather than coke to the ore. In remelting pig iron from the blast furnace for foundry use in making iron castings coke again is used as the fuel in cupola furnaces. In the conversion of pig iron into wrought iron and steel, the fuels used are coal, producer gas, natural gas, oil and sometimes charcoal.

SMELTING

The first process in the reduction of an iron ore is smelting in a blast furnace. American ores now used are practically all oxides, and the problem therefore is to break up the combination of iron and oxygen and obtain the iron in the metallic form.

Iron ores, although chiefly composed of iron and oxygen, always contain varying amounts of other substances, which although comparatively small, are of vital influence on the character of the iron produced from them. The most important of these additional substances are phosphorus, sulphur, silicon and manganese. The first two, phosphorus and sulphur are non-metals; silicon and manganese being metals. Sometimes other substances of more or less importance are also present. Phosphorus and sulphur have a harmful influence in steel when in more than certain amounts, the commercial limits being about 0.06% for each, and although cast irons for certain uses may contain these substances in much larger amounts, it must be remembered that pig iron from the blast furnace is the basis for steel making, and therefore a pig iron is demanded having the smallest possible content of these two substances. In steel the effect of phosphorus is to make it brittle when cold, and the effect of sulphur is to make steel brittle when hot. Every effort, therefore, is made to reduce the amounts of these two substances. Silicon and

manganese, on the other hand, have a beneficial influence under certain conditions and when in certain proportions.

It is impossible, of course, to obtain the ore without a proportion of gangue, or foreign earthy matter and rock, which becomes mixed with it in the course of mining. This is a troublesome and unavoidable impurity and must be eliminated in the blast furnace. The gangue generally consists of combinations of aluminum, silicon, oxygen and other substances. In order to make this gangue more easily melted, so that it may be liquid and thus readily disposed of, a flux is mixed with the ore and coke which goes into the blast furnace. This flux is limestone, and combines with the aluminum and silicon and makes a slag.

Chemical combinations, or changes in chemical combinations, depend largely upon the temperature, and the successful operation of a blast furnace means the proper regulation of the temperature in the various parts of the furnace.

The ore, coke and limestone, that is, the ore, fuel and flux, are charged into the furnace and air is blown in. Many complicated chemical changes take place among these materials, the exact course of which is not yet entirely understood, but it may be said that oxygen in the ore combines with carbon in the fuel and passes away as gas; the gangue and other foreign material combines with the limestone and produces slag. The molten metallic iron, being the heaviest, collects at the bottom of the furnace, while the molten slag floats on the top of the molten iron. The iron and the slag can thus be run off separately.

The chemical changes, of course, are not as simple as the above, but the final result is that metallic iron containing certain other substances, also slag, is obtained from the bottom of the furnace, and hot gases (which are utilized for different purposes) from the top of the furnace.

The phosphorus, sulphur, silicon, manganese and other elements which may have been in the ore also appear in the pig iron which comes from the blast furnace, having

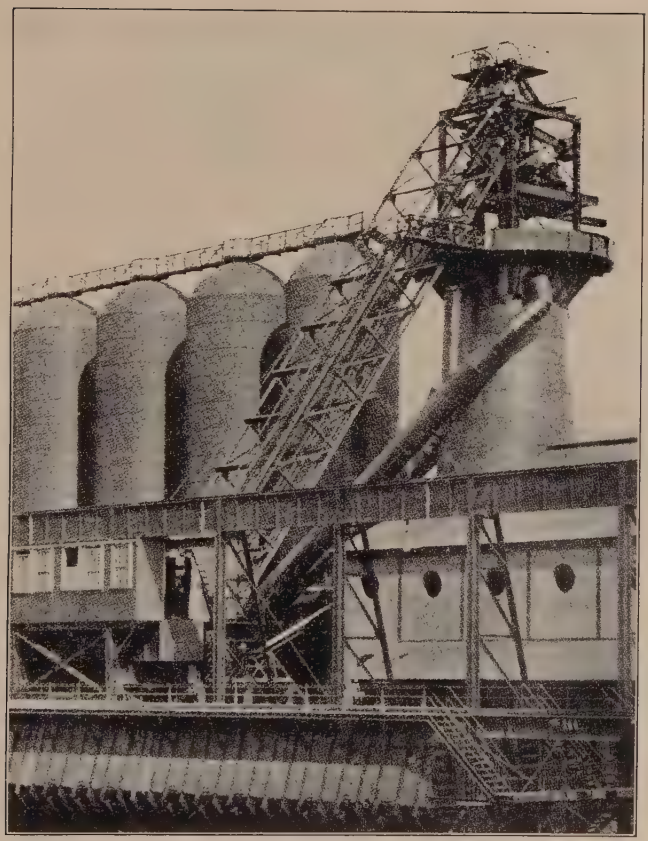
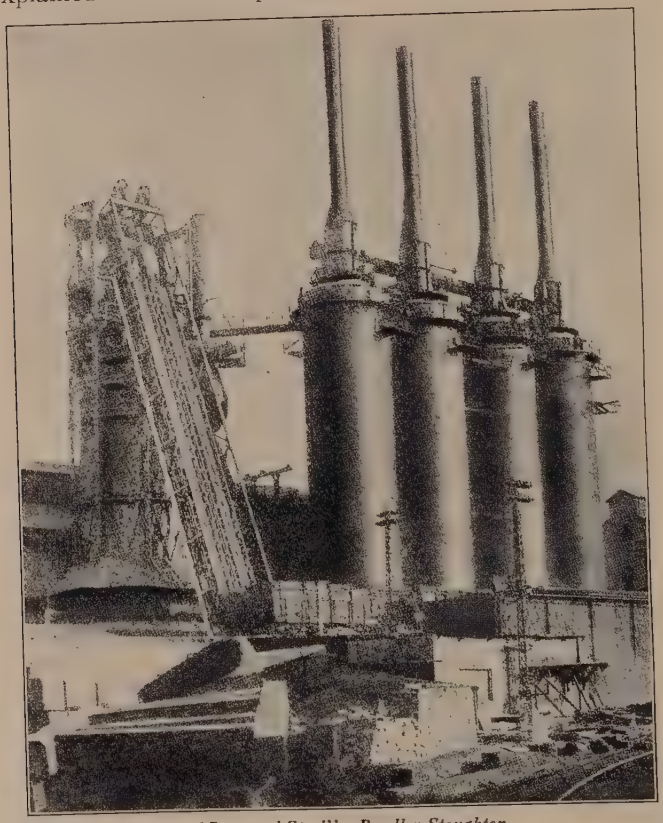


FIG. 4

BLAST FURNACE AND STOVES

been absorbed by the iron to a greater or less extent; all the phosphorus in the ore being included in the resultant pig iron, but the other elements may be in reduced quantities. The amount of phosphorus present in the ore, and consequently in the pig iron, determines the method that

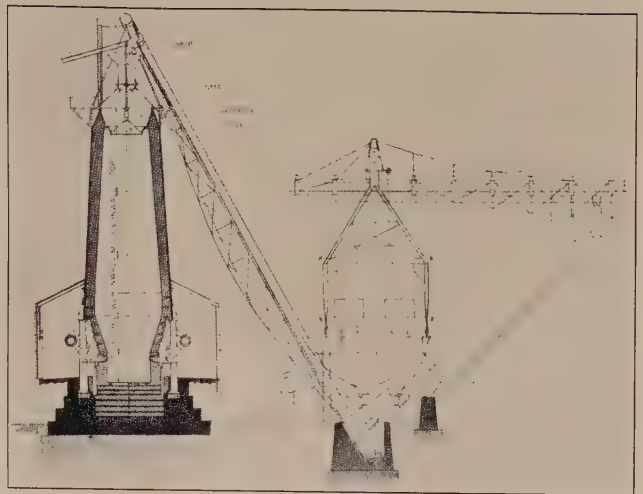
must be adopted in converting the pig iron into steel, and to make a satisfactory steel, pig iron with more than a certain phosphorus content must be treated in a special way. Ores low in phosphorus content will give pig iron known as acid Bessemer, and those higher in phosphorus give what is called basic pig iron. This will be further explained in the description of steel making.

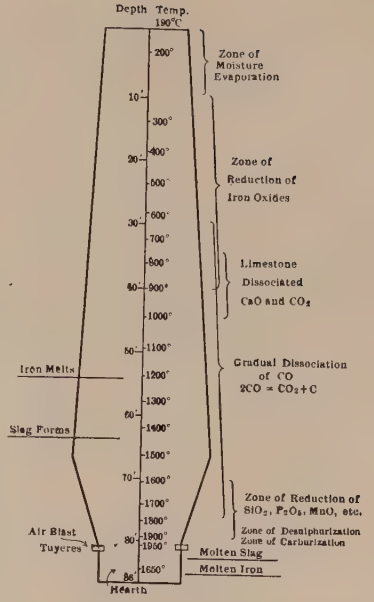


From "Metallurgy of Iron and Steel"—Bradley Stoughton

FIG. 5

BLAST FURNACE AND STOVES





From 'A Study of the Blast Furnace"—
Harbison-Walker Refractories Co.

FIG. 6
SECTION OF BLAST FURNACE

CHAPTER VIII

IRON AND STEEL

The reactions in the blast furnace are chemical, depending upon what is known as chemical affinity between certain elements at high and varying temperatures. The blast furnace in operation may be considered as a high column of iron ore, with its impurities and accompanying gangue, coke and limestone, all mixed together but being in individual lumps large enough to allow a fairly free passage of air up through the interstices between the lumps.

Near the bottom of this column, where the hot air of the blast is blown in, there is a very high temperature, and the oxygen of the blast unites with the carbon of the coke, thereby producing carbon monoxide gas which streams up through the column, accompanied by hot nitrogen from the blast. As the carbon monoxide gas becomes cooler it attains a condition in which it can unite with more oxygen, becoming carbon dioxide; it obtains this additional oxygen from the heated ore, or iron oxide, and thus leaves the iron in the comparatively pure metallic state which, on descending in the column, is melted at the high temperature near the entrance of the blast and flows down to the bottom of the column. The hot ascending gases heat up the limestone and cause it to dissociate into lime and carbon dioxide (lime being an oxide of calcium). The hot lime then unites with the hot gangue and forms a liquid or molten slag, which also flows to the bottom of the column. At certain parts of the column some of the carbon monoxide gas in cooling is converted into carbon dioxide and free carbon, and some of this carbon is absorbed or dissolved by the molten iron. There are other complicated reactions going on according to the heat in the various zones of the column. Where the temperature is very high,

for example, silicon, phosphorus and manganese, then in the form of oxides, dissociate from their oxygen and unite with or are dissolved in the molten iron.

Sulphur and phosphorus are the more troublesome impurities, and their behavior in the blast furnace is approximately as follows: Sulphur enters the furnace chiefly in the coke, and phosphorus enters chiefly with the iron ore, although the coke and flux also may contain small amounts of phosphorus. Both these elements are undesirable in pig iron, except that pig irons to be used for a certain class of iron castings may contain a considerable proportion of phosphorus with beneficial results.

Sulphur will unite readily with iron, forming sulphides of iron, and it is in this form that it is mixed with the coke, and as molten iron will dissolve iron sulphide, therefore a part of the sulphur contained in the furnace charge will appear in the resultant pig iron. Some of the sulphur, however, combines with the calcium of the limestone flux and goes away with the slag as calcium sulphide. Phosphorus, which was originally associated with the iron ore in combination with calcium or other elements will not unite with the slag. At the high temperature of a part of the furnace this calcium phosphate breaks up into a combination of calcium and oxygen (or lime) and phosphorus and oxygen (phosphoric acid), this being a reaction which appears to be dependent on the presence of silicon which is always there. A further reaction then takes place between the oxide of phosphorus and carbon, resulting in the production of free phosphorus, which immediately combines with iron forming an iron phosphide, and this phosphide is dissolved in the excess of molten iron. In this way all the phosphorus originally entering the furnace in the charge appears in the resultant pig iron.

The slag is composed of the gangue from the ore, the lime from the flux, the ash from the coke and a certain amount of sulphur and other impurities. The gangue is a mixture of oxides of silicon and aluminum, as is also the ash of the coke. The slag finally will consist of about

one-half lime and one-half silicates and aluminates, and the presence of so large a portion of lime gives it some commercial value.

A blast furnace as commonly employed today consists of a steel shell about ninety feet high, and varying in internal diameter from eight feet to twenty-two feet. It is lined with fire brick. Near the bottom air is blown in through nozzles known as tuyeres, which enter in a ring all around the furnace, while near the top a passage carries away the waste gases, and the top is closed with a bell-like arrangement, which also acts as a means of introducing the ore, coke and flux. The air which is blown into the furnace is heated to a high temperature by being passed through large chambers known as stoves, which are full of fire bricks and which have been previously heated by the waste gases from the furnace. In this way the heat from the waste gases is utilized, and there is a great saving of heat and hence economy in fuel, besides other advantages. A large blast furnace will produce 500 tons of pig iron a day, and for this production some 1,000 tons of ore, 550 tons of coke and 300 tons of limestone must pass through the blast furnace every twenty-four hours, and in addition to this some 2,250 tons of air must have been blown through the furnace during the same period. These figures give some idea of the scale of operations in iron smelting, and indicate what auxiliary plant and appliances for handling such masses of material are necessary to a blast furnace.

When a blast furnace is set in operation the process must continue without interruption. The starting up, or blowing in, as it is called, is a slow and expensive process, and nothing short of accident is allowed to interfere with the regular operation of a furnace until wear of the lining necessitates blowing out or shutting down. For this reason there must be a regular supply of ore, coke and limestone on hand, and therefore a blast furnace plant must have arrangements whereby very large stocks of ore and coke can be stored in such a manner that the labor of trans-

porting the material from the stock piles to the furnace is minimized.

The successful handling of a blast furnace is no easy matter and calls for long experience. Many things can go wrong. It is essential that the charging be regular and uninterrupted; it is even more essential that the iron be cast and disposed of when ready; derangement of the regular internal working of the furnace can occur; there may be internal explosions; scaffolds and cavities may form, followed by slips and sudden descents of large amounts of the unreduced charge into the hearth; the heating may be irregular, and any failure of the blowing arrangements also immediately stops the action of the furnace.

The molten pig iron from the furnace may be handled in different ways. It may be cast at once into sand molds, or into iron molds which work automatically, receiving the iron, cooling it and dumping the pig into bins or cars, or the iron may be taken in large ladles in the molten condition to the steel works and there charged while still in a molten state into Bessemer converters or open hearth furnaces. Occasionally some castings for commercial articles are made directly from the blast furnace. This, however, is unusual, but probably will be practiced more in the future.

The disposal of the slag is another matter of importance. The slag is usually run into large ladles, supported on trucks, and hauled to a slag dump where the ladles are discharged. The accumulation of slag has often been a source of difficulty, and at the present time it is utilized to some extent as a raw material for cement manufacture, its lime content making it suitable for that purpose, and as an aggregate for concrete or for making building brick.

The pig iron from the blast furnace is far from being pure iron. In addition to the substances other than pure iron mentioned above, the pig iron contains carbon, which is the element imparting to iron and steel the varying physical properties which make them of such economic use-

fulness, and thus it is the amount and condition in which this element carbon is present in the iron which converts it into cast irons, steels or wrought irons. Cast irons have present the most carbon, steels contain less, and wrought iron least of all. Pig iron as it comes from the blast furnace contains from 3.50% to 4.50% of carbon. To make iron castings, pig iron is remelted in cupolas or air furnaces, although some castings are now made directly from the pig as it comes from the blast furnace. The castings from the remelted pig will have practically the same carbon and phosphorus content as the pig, but may differ slightly in the sulphur, silicon, manganese, etc., content, due to reactions in the cupola furnace. Iron and carbon combinations (produced in the molten condition) classed as steels contain from about 0.05% to 2.00% carbon, but steels containing more than about 1.50% carbon are not of much use and are seldom made.

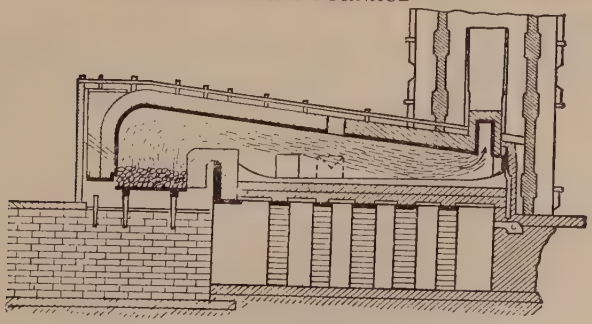
STEEL MAKING

The operation of converting pig iron into steel is one of regulating the carbon content and reducing the content of phosphorus and sulphur and other undesirable substances. In the history of steel making, the crucible process was the first, and the demand for large quantities of steel led to the discovery of the Bessemer process, which was soon followed by the open hearth process. At the present time the electric furnace is also used, but is adapted more to making high grade and special steels in comparatively small quantities than to producing large tonnages of structural or railway steel.

In the first production of steel, wrought iron or the purest iron obtainable was used, therefore the process of making wrought iron will be described before the subject of steel is taken up. Since wrought iron is pure iron containing a certain amount of slag, the object aimed at is the elimination of the impurities in the pig from the blast furnace. The process is carried on in a puddling furnace, which is a flat basin-like hearth heated by the flames from

a fire which are directed over the hearth by a low roof. The hearth is lined with a mixture of iron ore and iron oxides obtained from mill scale, and slags from previous operations are added with the pig iron. The pig iron melts and the furnace charge is stirred with rods, an operation known as rabbling. The purification of the iron then begins and first the silicon and then the manganese are oxidized to slag. By proper regulations of temperature and by stirring

PUDDLING FURNACE



From "The Metallurgy of Iron and Steel"—Bradley Stoughton

FIG. 7

SECTION OF PUDDLING FURNACE

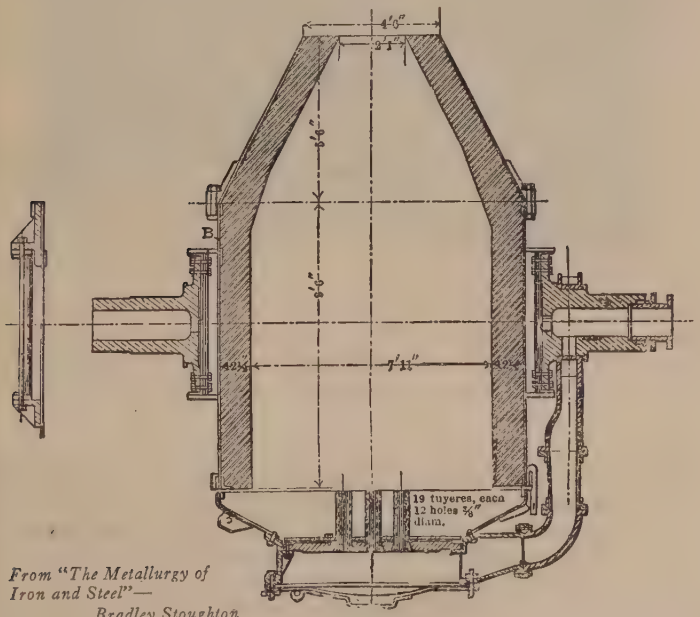
and mixing the molten iron, iron oxide and slag, the carbon, phosphorus and sulphur also become oxidized, the carbon going off as a gas and the other impurities entering into the slag. Some of the slag can then be removed from the furnace, but much of it remains mixed with the iron.

As these reactions progress the iron becomes purer, and the fact that a material when pure has a higher melting point than when contaminated with impurities, and since the temperature of the furnace is not raised, the iron will tend to solidify and will acquire a less fluid condition, becoming pasty and viscous. At this stage the iron is removed from the furnace in balls of a pasty mixture of iron and slag, which are hammered and squeezed to remove the slag. Wrought iron consists of fairly pure iron containing thin layers and threads of slag, and the squeezing and rolling tends to spread these films of slag more or less in one direction, giving the wrought iron a sort of fibrous texture. There may be from one to two per cent. of slag in commercial wrought iron.

Steel can be made by oxidizing cast iron at a temperature only sufficient to produce partial fluidity; a wrought iron is thus made by the oxidization of the carbon in the cast iron. This wrought iron is recarburized by heating it in closed vessels with carbonaceous material, and the resultant carburized iron, which thus becomes steel, is melted in crucibles and cast into ingots. Such a method is obviously incapable of providing the enormous amounts of steel demanded today, and although in former days steel was made which had a wonderful and even romantic reputation in tools and sword blades, the amount was very small, and it has been suggested that the reputation for these marvelous qualities was seldom founded on anything more substantial than a story-teller's imagination.

The great tonnage of steel produced today, however, is made by the Bessemer and open-hearth processes. The earlier of the two processes was the Bessemer process, which was so named because it was first introduced by Sir Henry Bessemer in England in 1856. It is said that

Bessemer, who was interested in the manufacture of projectiles, was watching trials of projectiles near Paris, and overheard a French officer remark that some better material than then known was very much needed for making guns. Bessemer himself related that during his solitary ride from the trial grounds at Vincennes to Paris he resolved to do what he could to improve the quality of iron for gun making. Shortly after this Bessemer announced his process of converting iron into steel, which is essentially, that if air is blown through molten pig iron, the impurities—namely, the carbon, silicon, phosphorus, sulphur and manganese, will unite with the oxygen of the air and be oxidized; or, in other words, burn before the iron begins to unite with the oxygen. A vital part of the



From "The Metallurgy of Iron and Steel"— Bradley Stoughton

FIG. 8
SECTION OF BESSEMER CONVERTER

From "The Metallurgy of Iron and Steel"—Bradley Stoughton

FIG. 9

CONVERTER DURING BLOW

discovery was that the heat produced by this oxidization or burning is sufficient to maintain the iron and slag in a molten condition without the use of other fuel. Steel, therefore, can be made by thus obtaining a pure iron in a molten condition, and then adding a proper proportion of carbon (and if an alloy steel is required, other substances) to the pure iron. The process is carried on in a converter, which is a vessel lined with fire brick and capable of being tilted or held at any angle. When molten pig iron from the blast furnace is poured into the converter and a blast of air blown through the molten metal the oxidization or

burning of the impurities is evidenced by flames issuing from the mouth of the converter.

The progress of the reactions in the metal is judged by the appearance of the flame, and the blowing is stopped when the flame indicates that the burning of the impurities has proceeded far enough. The carbon content of the metal is then brought to the correct proportion by the addition of spiegel, which is pig iron containing a large amount of manganese, or ferro-manganese, which is pig iron containing a still higher percentage of manganese, both of these, of course, also containing high amounts of carbon. This spiegel or ferro-manganese is added in the molten condition, being previously melted in a cupola furnace, which is usually located near the converter. The process is not as simple as may appear from this elementary description, and difficulties arise in the elimination of phosphorus and sulphur.

It has been noted that in the blast furnace all the phosphorus came out in the pig iron, the phosphorus having first been oxidized and then reduced by carbon to free phosphorus, which immediately combined with the iron. In the process of steel making in the converter the phosphorus is again oxidized, but except under certain conditions it cannot be made to remain as an oxide and join with the slag and thus be eliminated. Unless it can be made to enter the slag it will give up its oxygen to some of the iron, forming iron oxide, and combine with iron again. This is accounted for by the nature of the slag and of the converter or furnace lining. If the slag is basic, the phosphorus will combine with it; if it is acid, it will not.

The combination of phosphorus and oxygen produces a compound which is known chemically as an acid. An acid will not unite with another acid, and hence if the slag is acid in character the phosphorus will not unite with it. Pig iron contains a certain amount of silicon which is oxidized to silica, and moreover the lining of the converter or furnace may be made of fire brick, which is also chiefly silica. Now silica is acidic in character, and therefore

will not unite with the acid oxide of phosphorus. This difficulty is overcome by what is known as the basic process. By lining the converter with a basic material, such as dolomite and adding a certain amount of lime, the slag becomes basic in character, and therefore will readily combine with phosphoric acid, and produce a phosphate of calcium, which is removed with the slag. It would be possible to create a basic slag with an acid lining in the converter or other furnace, but then there would be a reaction between the slag and the lining which would quickly destroy the lining.

No elimination of phosphorus, therefore, is attempted in the blast furnace. There are certain iron ores which contain so little phosphorus that the pig iron produced from them can be converted into steel by an acid process which still contains phosphorus only to an amount which is not harmful. This pig iron, sometimes called Bessemer pig, can be used in converters and also open-hearth furnaces which are lined with gannister or silica fire bricks, and in which the slag can be allowed to be acid in character.

When, however, the amount of phosphorus is so great that it must be reduced in order to make a satisfactory steel, the linings of the furnaces used and the slags obtained must be made basic. There are thus acid converters and basic converters, acid open-hearths and basic open-hearths. In the acid converters and open-hearth furnaces, phosphorus cannot be eliminated. In the basic converters and basic open-hearths it can be eliminated. When the basic process must be used, the linings of converters or hearths are made of dolomite, which is a natural basic material similar to limestone, and considerable quantities of limestone are added to the furnace charge. Basic converters are not used to a great extent in the United States of America, but are largely employed in Germany.

In the open-hearth process impurities are oxidized to slags in fundamentally the same way as in the Bessemer process, or indeed as in the puddling process.

The open-hearth furnace consists of a large shallow basin, called the hearth, lined with silica fire brick if it is an acid process, or with dolomite if a basic process. The hearth has a low roof or cover, and is heated by flames and hot gases passing over it, which proceed from the combustion of a fuel usually gaseous, and this may be natural gas, producer gas or atomized oil.

What is known as the regenerative principle is adopted to obtain high temperatures economically. Similar to the method used at blast furnaces, the hot gases from the furnace are made to pass through chambers containing checker work of fire brick which absorb heat from the waste gases and become very hot. When hot, the waste gases are diverted into other similar chambers, and air for combustion is caused to pass through the hot chamber and thus becomes very highly heated. This hot air is then mixed with the gaseous fuel, which itself is heated in a similar way and burnt. The regenerating chambers are used in rotation just as the stoves of a blast furnace are used.

Pig iron, scrap steel, iron ore and limestone constitute the furnace charge for a basic furnace; for an acid furnace the limestone is omitted, its function being to form a basic slag which will retain the oxidized phosphorus and form calcium phosphate.

If limestone was added to an acid furnace it would immediately attack the silica of the acid lining to form calcium silicate, and in a short time would destroy the furnace lining.

When the charge has become molten the CO rising from the bath bubbles through the melt, acting as a mechanical stirrer, and bringing the metal into intimate contact with the oxide and lime in the slag, by which means the phosphorus is oxidized to phosphate of lime. Action subsides as the carbon content diminishes.

The iron ore of the charge reacts with the carbon of the pig to form carbon monoxide, which also boils violently at first but diminishes as the carbon of the bath diminishes.

When the carbon has reached or passed the given percentage desired, the phosphorus has practically all gone into the slag, while the silicon and other elements which oxidize readily have been nearly eliminated. At this point the steel is quickly analyzed and additions made to bring the carbon and alloys up to the required specifications.

It is important in the production of good steel that when tapped it should be found free from non-metallic impurities such as slag, gases, etc. This is a question of

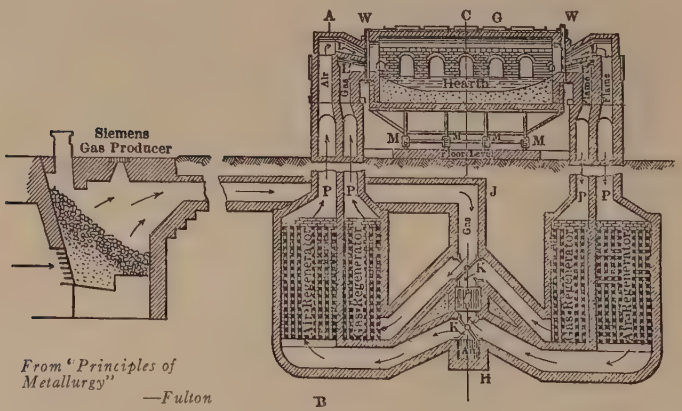


FIG. 10

SECTION OF OPEN-HEARTH FURNACE

careful manipulation, and the using of sufficient reducing agents, such as aluminum, ferro-silicon, ferro-manganese, etc., to take care of any excess of oxygen present in the steel. These agents are known as deoxidizers.

The open-hearth process has advantages over other conversion processes in the large amount of steel which can be made at one heat by the utilization of large proportions

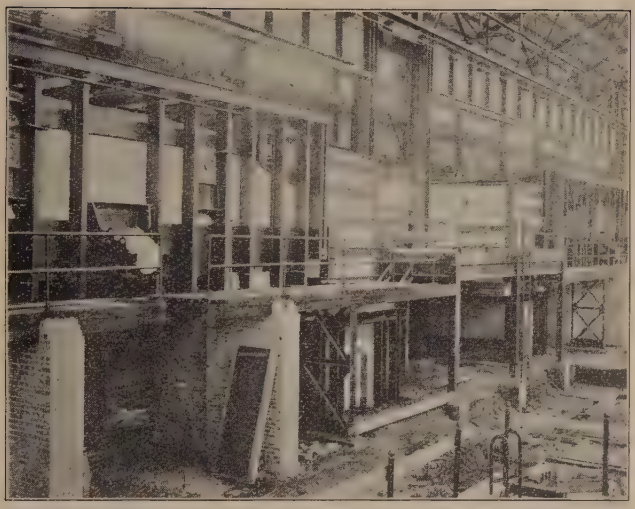


FIG. 11
OPEN-HEARTH FURNACE

of scrap material and in the precision of control of reactions. As previously stated, the open-hearth can be acid or basic. The greatest tonnage of steel is produced by the basic process.

In the electric process, heat is produced by the passage of an electric current, and therefore it is possible to obtain a neutral condition in the furnace, or, in other words, a condition neither oxidizing or deoxidizing. The reactions may be basic or acid, and in principle are the same as in the open-hearth. Very high temperatures are possible, and the elimination of both sulphur and phosphorus can be accomplished very satisfactorily in the electric furnace, enabling these elements to be reduced to almost any limit.

The foregoing remarks have described in a very brief way the production of steel of a desired composition in the

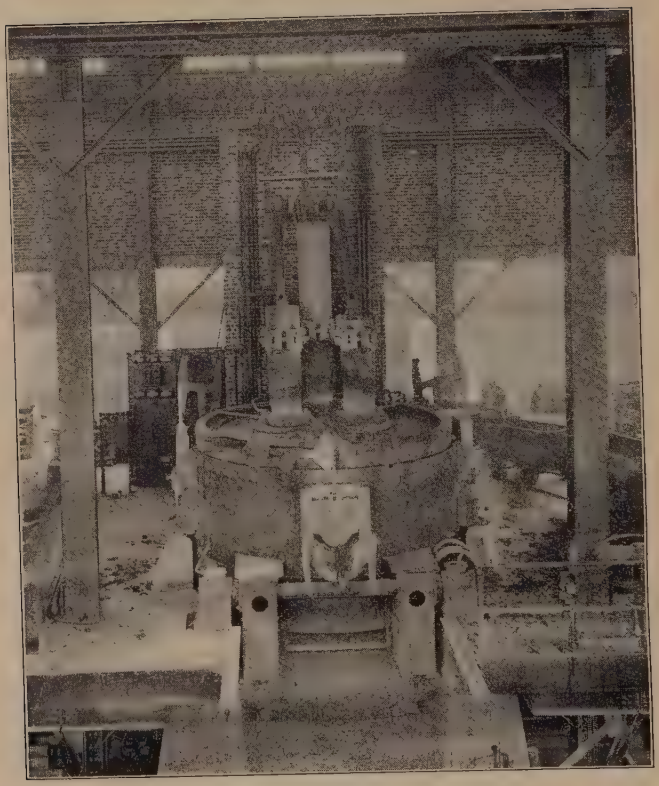


FIG. 12

ELECTRIC FURNACE

ingot form, but steel in the ingot is far from having the physical properties which are usually demanded of it. Apart from the processes which are required to shape the steel into the proper form and dimensions, mechanical and heat treatments are necessary to put the steel into the proper physical condition for the service which is required

of it. In order to understand the effects of mechanical and heat treatment on steel a study must be made of its constitution, and an inquiry into exactly what steel is, and what internal changes take place when it is subjected to treatments of various kinds. This study is the most difficult of all branches of the metallurgy of iron and steel, and although much has been written on the subject it has not always been described or interpreted simply or clearly.

Metals are, when in the solid condition, crystalline; that is to say, made up of a mass of crystals which vary in size and interlock and cling together. Most known material can exist in three conditions, depending on the temperature; these conditions are: solid, liquid and gaseous. In considering iron and steel we need only be concerned with the solid and liquid conditions. At a high temperature iron and steel are liquid, and at lower temperatures they change from a mobile and fluid state to a solid and more or less rigid aggregate of small crystals. An important point to remark is that after solidification, changes of a vital nature continue to take place as the solidified metal continues to cool, and it is by controlling these changes that steel is made to acquire those properties of strength, ductility and hardness which may be required.

It has been stated previously that cast iron and steel are not pure metals, but are really alloys of iron with carbon, and it is the manner in which the carbon is associated with the iron that determines the character of the steel or cast iron of commerce.

Two or more different elementary substances may be associated with each other in various ways; they may be mixed mechanically, one may be dissolved, or in solution in the other, or they may be in definite chemical combination with each other. Carbon and iron are thus associated, for disregarding the other impurities, such as phosphorus, sulphur, silicon and manganese, which are practically always present, the numerous classes of steel may be considered as associations of iron and carbon in the following

proportions: Extra mild, very low carbon or dead soft steel containing not over 0.10% of carbon; low carbon, mild or soft steel, not over 0.25% of carbon; medium high carbon or half hard steel, not over 0.60% carbon; high carbon, or hard steel, containing more than 0.60% carbon; very high carbon, very hard or extra hard steel, over 1.25% carbon.

Wrought iron differs from steel in the method of its manufacture, but may be identical in composition with a very low carbon steel. Cast iron, on the other hand, contains greater proportions of carbon than steel, and usually has from 2.50% to 4.00% carbon content.

Annealed steel or iron at atmospheric temperature consists of two distinct substances, one ferrite, which may be considered as pure iron; and the other cementite, which is a chemical combination of iron and carbon. These two substances, which are crystalline, associate together in certain definite ways according to conditions; these definite associations have been given certain names, but it is not necessary to use them in so elementary an exposition as is here given. Ferrite is soft and ductile, cementite is hard and brittle. In alloys of iron and carbon, when in the annealed state the carbon present is always united with iron in the definite chemical combination mentioned above, that is as cementite, and in steels in which the carbon present is less than .85% there is not enough carbon to combine with all the iron and so there is more or less free iron, that is, ferrite present. As the carbon content increases, the amount of ferrite decreases and the cementite increases. In considering the comparative qualities of wrought iron, low carbon steel, high carbon steel and white cast iron, they shade from the softness and ductility characteristic of ferrite to the hardness and brittleness characteristic of cementite. In alloys of iron and carbon having the greater carbon content, the carbon may also be present in the form of free graphite, as well as in combination with iron as cementite, and this is the case in gray cast iron. The minute particles of graphite impart

the gray color to the cast iron, and it is this graphite which causes gray iron to be so readily machinable. The foregoing remarks apply to steel and iron when at about the atmospheric range of temperature.

It has been stated earlier in this article that chemical combinations as well as physical conditions are dependent on temperatures, and this is shown clearly in the case of these iron and carbon associations. When steels, that is, when certain associations of iron and carbon are raised from atmospheric temperatures up to temperatures slightly above a red heat, some very important changes take place in the manner of the association of the iron and carbon at certain temperatures, depending upon the proportion of iron and carbon that may be present. The temperatures at which the changes begin to take place are called the critical points, and the temperatures between the critical points are called critical ranges.

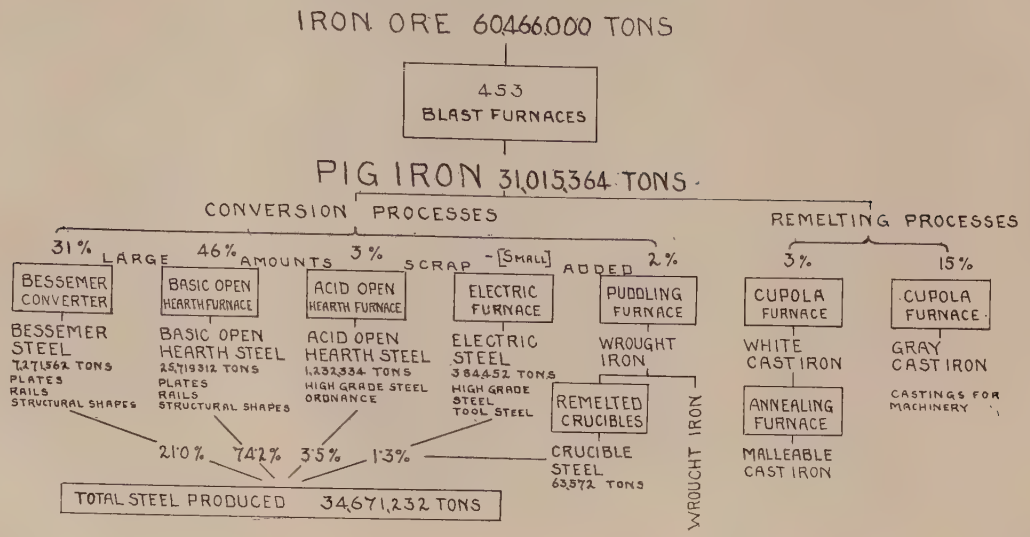
In cooling hot steel from near its melting point to atmospheric temperature, similar critical points occur. The true significance of the critical points has been found through the study of metallography. The changes which take place at the various temperatures require more or less time in order to be complete, and it has been found that by varying the rate of change of temperature the changes occurring can be arrested in a more or less complete state.

The associations of iron and carbon at atmospheric temperature produce substances having certain physical characteristics, while at higher temperatures and in the critical ranges other physical characteristics occur. By rapid cooling the change of the associations from one to the other may be more or less arrested, and consequently an association at atmospheric temperature is attainable having different physical characteristics from the characteristics which would be normal under conditions of slow cooling. The critical points vary as the carbon content varies, and also may be affected by the presence of other metals, such as manganese, tungsten, etc. It will, therefore, be seen that there are many factors to be considered in prescribing

a treatment for a steel so that certain definite properties may be obtained, but the foregoing outline will indicate the principles by which the desired degrees of hardness, strength and ductility may be gained by subjecting steels of known composition to carefully prescribed heatings and coolings, or various operations known generally as heat treatments.

An important factor in the quality of steel is relative to the crystalline condition of the material. The iron and carbon associations are crystalline, and, as soon as molten steel cools to its solidification temperature, minute crystals begin to form. These crystals increase in size as solidification proceeds, and the slower and more undisturbed the cooling the larger the individual crystals may become. Fine and uniform crystals give to steel the best qualities, and its mechanical treatment, such as forging, pressing, hammering and rolling, breaks up the large crystals formed during solidification. Working steel above the critical temperature is called hot working, and normally all working should cease before the steel has cooled below a certain temperature, viz., the critical range. At the critical range complete recrystallization takes place in the solid state. Working below the critical range distorts the crystals and produces cold worked material such as cold rolled bar stock. It will thus be seen that forging, hammering, rolling, etc., have an important effect upon the internal structure as well as upon the external shape of the steel.

FLOW SHEET OF MANUFACTURE OF IRON AND STEEL
U.S.A. 1919



CHAPTER IX

MECHANICAL TREATMENT OF STEEL

The principal purpose of working steel is to shape it into the desired form. Its structure and physical properties are dependent on the care in working and the heats used. The mechanical working, aside from machining, is classed under two heads, namely, Hot and Cold Working.

FIG. 13

Spring steel showing slag

The finest grain size obtainable is undoubtedly that existing just as the steel has passed through the critical range on a rising heat. Hence, starting out with steel just below its solidification point on undisturbed cooling the grain size increases until the cooling has passed through the critical range, and the grain size at this stage will be the resultant size at the cold temperature. Taking the same piece of steel, for instance, having a coarse structure, on heating there will be no change in grain size until the critical range

is reached, then the coarse crystals break up and at the upper critical point form the finest natural structure. Continued heating, however, above this point will again give the coarse grain structure.

As we have stated, undisturbed cooling is a condition necessary for crystal growth; a coarsely crystalline structure, however, can be partly prevented or broken up by vigorous hammering. If this hammering ceases above the critical range, coarse crystallization again sets in, and the higher the temperature above the critical point at which the work stops, the coarser the structure will be. The finishing temperature in working should always be for the best results at or just above the critical range.

The question then arises: Why not continue working the steel until it is cold? This would be a detriment, inasmuch as the grain structure is formed in the critical range and "cold working" below critical range causes distortions and strains to set up in the steel which result in decreased ductility and even brittleness. This effect is more pronounced the lower the temperature below the critical point at which the steel is worked. Mechanical working above the critical range provides a means to shape steel to form by forging, refines the grain size and tends to impart decidedly more density than the steel possessed originally when rolled at the mill.

It will be seen from the following illustrations what is meant by mechanical working and the effect it has on the grain structure.

It is, of course, difficult to show this effect by means of photo-micrographs so the pen is resorted to as a means of explaining the points more clearly.

Fig. 14 shows the grain of steel in the ingot, forgetting for the time being the possible conditions entering into steel in this form, such as segregations, pipes, etc. The illustration is just a cross section, before working, of a low carbon forging steel. The subsequent illustrations are self-explanatory; namely, Fig. 15 shows the ingot rolled or hammered, and the reduction in the size of grain is seen.

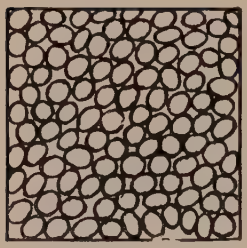


FIG. 14
Ingot of Steel

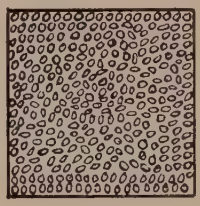


FIG. 15
Rolled and Hammered

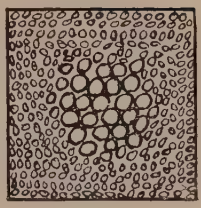


FIG. 16
Light Blows

Fig. 16 shows the effect of improper working, the result of light blows on the surface, which do not extend their reducing force to the center.

FIG. 17
Annealed

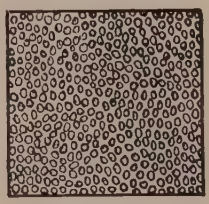


FIG. 18
Properly Hardened

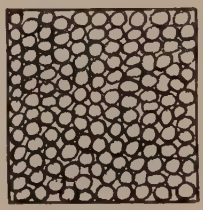


FIG. 19
Overheated

Annealing (Fig. 17) promotes the adjustment of the grain size, and relieves strains set up by working.

The steel, after correct working, is now in a condition to be hardened, and a fine, even, silky grain is the result, if the proper temperature has been used in hardening (Fig. 18). If too high a temperature is used in hardening, a coarsely crystalline formation appears (Fig. 19), which can only be entirely reclaimed by a subsequent heat treatment, providing the steel has not been burned.

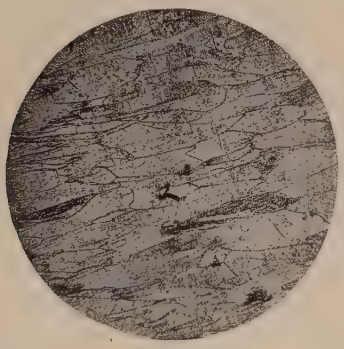


FIG. 20
Elongated Crystals

A simple example of cold working is plainly shown in the three photo-micrographs, Figs. 20, 21 and 22.

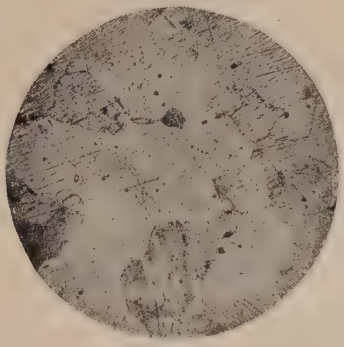


FIG. 21
No Distortion of Crystals

These figures show the grain distortion at points A, B and C respectively, of a piece of low carbon Swedish iron when bent double on itself (Fig. 23).

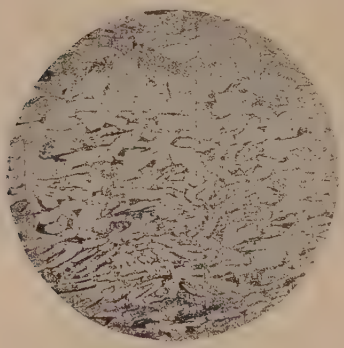


FIG. 22
Compressed Crystals

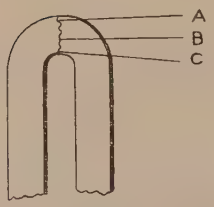


FIG. 23
Low Carbon Swedish Iron bent double on itself, showing location of sections illustrated in Figs. 20, 21, 22

There are three methods commonly used for working steel: rolling, hammering and pressing.

For reducing ingots to blooms and to shapes of a uniform cross section, such as round or square bars, rolling is generally the process used.

For irregular shapes or individual articles, such as gear blanks, etc., either pressing or hammering is used, hammering being the more common method.

In reducing a section by hammering the reduction is effected by the absorption of the hammer blows causing the metal to flow.

If the section is large as compared to the weight of the hammer, the effect of the blow will not penetrate very deeply and the structure in the center of the section will receive no beneficial working.

Since the hammer transmits its force with great suddenness its effect is limited to a small depth, and to obtain a complete working of the section either a hammer must be heavy or several beatings are required.

The rolling mill draws the section between the rolls and works it through to any required reduction, depending on the number of times it is passed through the mill. The rolling mill practice is always to work all operations to the center, except perhaps in the case of a mill reducing ingots to blooms.

The press being slow acting and transmitting its force to the center of the section is metallurgically the ideal method for reduction. It is much slower and more expensive than a rolling mill, and hence it is not used as much as the mill, although in the higher grade steels it is superseding the heavy hammer.

For the production of individual pieces, such as crankshafts, gear blanks, etc., hammers or forging machines are used, which form the shape desired by working a heated billet between two dies.

The dies used are shaped to form the blank required, with a relieved section all around the edge of the form to take care of the surplus metal squeezed from the billet when the dies are brought together. The bottom die is fixed, while the top die, being attached to the hammer of a steam or drop hammer, is movable. To prevent scale being forged into the finished piece, it is necessary to blow the dies clean with a high pressure steam or air hose.

In forging, it is necessary that the billets should not be overheated, so that there is no chance of burning, and the finishing temperature of the piece should be as close as possible to the critical range to insure maximum grain refinement.

Rounds and shapes, such as wire rods, etc., are generally cold drawn, the rod or bar being pulled through a die having the section which it is desired to maintain. Here the metal is reduced in size in the cold state, and the reduction is due to distortion of the ferrite, which causes some hardening and brittleness.

For cold drawing the dies used must be of great hardness and a special lubricant used.

For hot working (drop forging), dies made from .50%-.60% carbon, heat treated low chrome nickel steel give good results.

For cold drawing dies, water quenched 1.25% carbon steel having some chromium is used considerably.

In all hot working operations the force of the pressure or impact should penetrate sufficiently to affect the grain structure of the interior of the piece as well as the exterior. If sufficient force is not used, as by employing too light a hammer, the effect will be shown by the surface of the piece. This will appear convex or bulged if the working has penetrated to the center, and concave if the interior has not been extended as much as the exterior.

Drop forgings are ordinarily small in relation to the hammer used, and little trouble is experienced from the lack of working through the piece. Here it is more important to guard against over-heating, since the forging operation does not require much time, and the grain size will not be reduced if working is stopped much over the critical range.

In cold drawing the metallurgical difficulties are few, it being mainly important that too much reduction is not made, so that the piece is not made unduly brittle.

CHAPTER X

METALLOGRAPHY

In the previous chapters we have but mentioned the microscopic structure of metals, and although we have had occasion to speak of the chemical composition of alloys such as steel, it may here be said that an accurate chemical analysis alone of a commercial metal or alloy, although useful and necessary, will not give definite information as to the physical properties of that material. In other words, two pieces of steel having widely different tensile strength, hardness, ductility, etc., may be chemically analyzed and found to have exactly the same composition. The chemical analysis, or what is called the ultimate analysis, does not give any idea of the physical intimate structure of the material, nor does it indicate that certain chemical combinations may exist in different physical forms. By the use of the microscope, however, a study of the minute structure of the metal may be made and thus an idea of the intimate physical characteristics of a piece of steel may be obtained, and from the first attempts to study this true structure of iron and steel by means of the microscope there has developed the branch of metallurgy, which deals with the internal structure and constitution of metals, which is now called Metallography.

The discovery and development of metallography has been of the utmost practical as well as theoretical importance to the metallurgy of iron and steel, and has marked an advance of as great significance as the adoption of the hot blast in iron smelting or Bessemer's process in steel conversion.

In the case of many metals, but most particularly in the case of iron and steel, the work of the metallurgist may be considered as divided into two consecutive parts. The

first is the production of a material of the right composition, or containing the proper proportions of the proper elements. This can only be accomplished with the aid of accurate chemical analyses. After the production the material having the desired composition, the second part of the metallurgist's work begins, which is the treatment of this material in such a way that it may acquire with certainty those physical characteristics which will adapt it to the use for which it is intended. The discoveries made by the study of metallography have been the means of putting these treatments on a scientific basis, and while in the past many highly successful results were obtained by various methods of hardening, annealing and all sorts of heat treatments, these successes were obtained entirely by hit and miss methods until the microscope and the metallographist showed what was the actual result of these treatments, and what really took place in the constitution of the metal when subjected to treatment.

The technique of the miscroscopic examination of metals is difficult and calls for expert manipulation. Metals are not transparent, and cannot be examined by transmitted light as is the case with many other materials submitted to microscopic examination. Metals must be illuminated by reflected light and the surfaces of the specimen must be very specially prepared. Elaborate microscopes, with means for illumination, holding of the specimen and complete photographic attachments are now common on the market and do not call for particular description. The specimens to be examined must be polished and treated with various reagents, which act differently on the different constituents of the metal, and as a result the surface of the specimen to be examined reflects light in a manner which permits of distinguishing the various constituents that may be present.

THE MICROSCOPE

The type of microscope used in the study of opaque objects like metals necessarily differs somewhat from that

used for transparent objects such as are found in bacteriology and petrography. In the latter case the beam of light is reflected by mirrors through the object, but in the former the light is reflected onto the surface of the specimen. If the light is reflected perpendicularly onto the specimen, the illumination is called vertical, and if the light is directed obliquely onto the specimen, it is called oblique illumination. Sketches of the different methods just described are shown here:

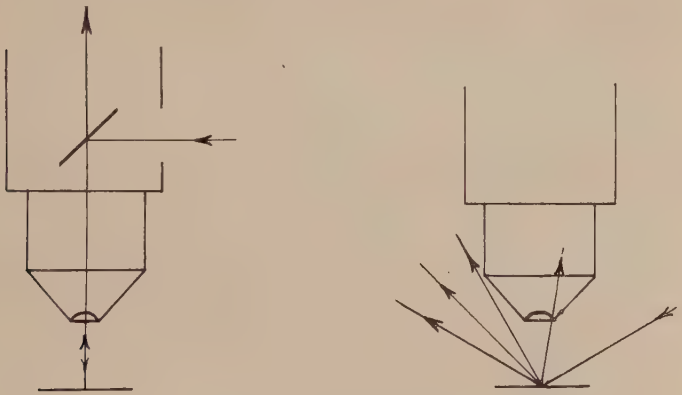


FIG. 24
METHODS OF ILLUMINATION

PREPARATION OF SPECIMEN FOR MICROSCOPICAL EXAMINATION

In making a microscopic examination of a metal, a small piece is taken and a face filed or ground as flat and smooth as possible. The specimen must now be polished, the object being to obtain a small flat surface absolutely free from microscopic scratches or marks. The specimen is polished by fine emery and tripoli powder mixed with water, in the form of a paste spread on linen or woolen cloth, the polishing being done in progressive stages, end-

ing with a careful light rubbing with rouge and water. During polishing the specimen is frequently washed in water and examined for scratches. Polishing may be performed by hand or by power, and very small specimens sometimes need to be mounted in holders.

Although a microscopic examination of a simple polished surface will show certain interesting features, the minute structure of the metal is made apparent by etching the polished surface with some reagent which acts with different intensity on the different constituents, hence by treating the whole surface with the reagent the different constituents are etched to different depths, and when the etched specimen is observed under the microscope while light is thrown on the surface, the light is reflected differently according as the etching is different, and a sectional outline of the small masses of the various constituents is clearly seen. Many different etching agents are used, and considerable skill may be exhibited in obtaining satisfactory results. Other methods besides etching may be employed to bring out certain features, thus it is possible, with the use of a copper depositing reagent, to coat certain constituents with a film of copper while others remain uncoated, or by careful heating, various constituents may be oxidized and so acquire distinguishing tints.

The foregoing outline describes the practice which is used in metallurgical laboratories to examine metals, particularly iron and steel, and which is employed to a very great extent in prescribing and checking heat treatments by which the physical properties of metals demanded by engineers are obtained.

CRYSTALLIZATION

When a substance passes from the liquid to the solid state crystallization usually takes place; that is, the molecules of the substance arrange themselves so as to form small solids of geometrical outline. If this growth is unimpeded so that the solids assume regular geometrical outlines, the resultant crystals are said to be idiomorphic;

but when, as in metals, crystallization starts from many different centers, this growth is impeded, and imperfect crystals are formed called allotriomorphic crystals.

A polished and etched specimen under the microscope shows up these crystals, and their size, state and character can be ascertained. It has been through the careful examination of microscopic specimens that the following peculiarities of iron and steel have been discovered.

STRUCTURE OF A PURE METAL

The photo-micrograph below shows the structure of an almost chemically pure iron etched about ten seconds with a 4% solution of nitric acid in alcohol. If the metal had been etched slightly only the boundary lines (being more soluble in the acid) would be visible, and there would not be the variation in color of the grains noticed here. It is not definitely known what the substance is which is between the grains, but the theory most widely accepted is that as the crystals grow in the molten mass each gathers to itself more and more of the surrounding material, until finally there is so small a film left that it cannot assume the orientation of any of the grains and therefore solidifies without shape or in an amorphous condition. The specimen from which this photograph was taken has been etched somewhat deeper, so that in addition to the boundary lines of the grains the variation in color may be seen. Each of these grains are made up of small cubic crystals (as is usually the case in metals) the axes in each grain all point the same way but differently in different grains. It is due to this phenomena of varying orientation that there is a dissimilarity in the color of some of the grains, the light striking the irregular surface of the specimen, caused by the facets of the cubes being at different angles, is in some cases reflected out of the tube of the microscope.

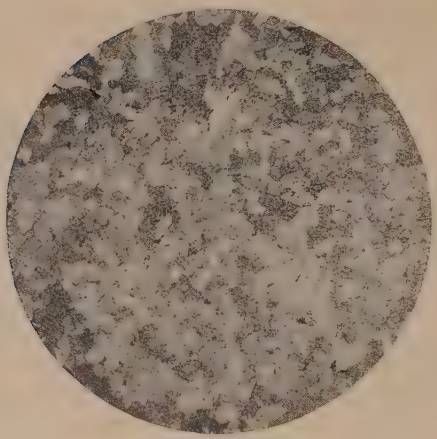


FIG. 25
Almost Pure Iron Magnified 100 Times

METALS AND ALLOYS IN GENERAL

Almost all the metals that are used in commercial practice are alloys essentially of two elements. Other elements, of course, are added which have been found to impart to the alloy valuable physical properties, but these are usually only added in very small quantities and may be considered individually. Thus, brass is an alloy principally of copper and zinc; bronze an alloy principally of copper and tin; and steel an alloy principally of iron and carbon.

EQUILIBRIUM DIAGRAMS

Equilibrium means, simply, the condition of a system or mixture with regard to existing conditions. An equilibrium diagram then is a curve which shows all the relations between composition and temperature. These diagrams are obtained by recording with a suitable instrument all the absorptions of heat on heating, or, which is more convenient, all the evolutions of heat on cooling of

many alloys in the same series of known chemical composition, and then by plotting these observations with the temperatures as ordinates and the composition as abscissae. The great importance of a clear understanding and ability to interpret these diagrams cannot be too greatly emphasized, because these curves form the basis of metallurgy—as well as metallography.

There are three main types of equilibrium diagrams or fusibility curves, as they are sometimes called, which either separately or combined cover practically all alloys, viz., (1) the curves of those binary alloys whose component metals are completely soluble in each other when solid, (2) whose component metals are insoluble in each other when solid, and (3) whose components form a definite compound.

In order to understand how these diagrams are constructed it is first necessary to examine the curve of a pure metal as it cools from above its melting point to atmospheric temperature.

It is seen in curve "a," Fig. 26, which is a typical curve, that as the metal cools the temperature decreases at a constant rate, except that as the solidification or freezing point is reached there is an interval of time in which the temperature stays constant. A curve similar to this would

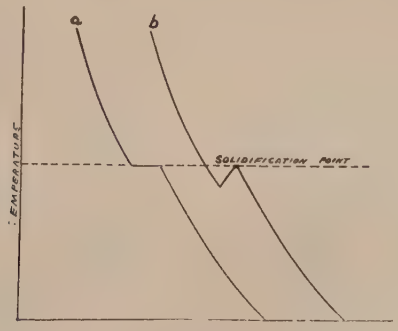


FIG. 26

Typical Cooling Curve

be obtained on heating. It should be mentioned here that if conditions are suitable (*e. g.,* if the metal is undisturbed while cooling) the cooling curve may take the form shown in curve "b," Fig. 26. This phenomenon is known as surfusion or undercooling.

In Fig. 27 is shown the typical cooling curves of binary alloys whose component metals are completely soluble in each other in the solid state, *e. g.,* gold and platinum.[1] It may be seen that there are now two evolutions of heat occurring at "A" and "B." Obviously, then, the alloy solidifies over a range of temperature and not at a single point, as in the case of a pure metal. From this it follows that between these two limits the metal is partly liquid and partly solid. By making several alloys of known content and plotting their cooling curves and then joining the points where evolutions of heat occurred, a complete diagram is obtained, as shown in Fig. 27. The line which limits the liquid region is called the "liquidus," and the line below which the metal is completely solid is called the "solidus." Under the microscope the structure of metals belonging to this group appears the same as that of a pure metal.

FIG. 27

Cooling Curves of Binary Alloys

[1] It cannot be foretold without previous knowledge just what metals fall in these different categories.

Fig. 28 shows the typical equilibrium diagram obtained by plotting several cooling curves of alloys whose component metals are insoluble in solid state. Here, again, it may be seen that there is a solidification *range* and not a solidification point, and also that the solidus is a straight line indicating that the alloys become *completely* solid at a single temperature. There is one point, "E," where the liquidus and solidus unite, showing that the alloy solidifies at a single temperature as in the case of a pure metal. This point is called the eutectic point (eutectic means "lowest melting point"). Figs. 29[1], 30[1] and 31[1] show the typical structure of alloys taken at the points A, B, and E in Fig. 28.

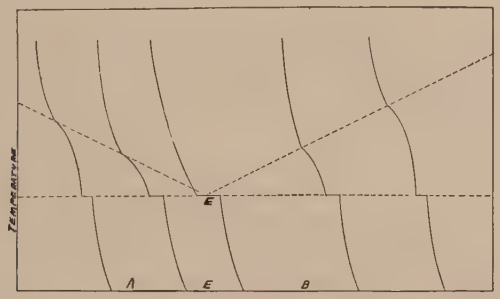


FIG. 28

Equilibrium Diagram for Two Metals Insoluble in Solid State

FIG. 29

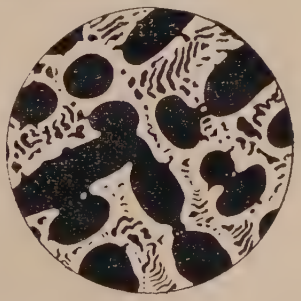


FIG. 30

[1] After Sauveur.

FIG. 31

In the first case the excess constituent (above the eutectic ratio) has crystallized out, leaving the eutectic to solidify last; in the second case the resultant solid is 100% eutectic; and in the third case the other metal of the alloy, now in excess (above the eutectic ratio) has solidified out, leaving the eutectic to freeze last. This eutectic is made up of alternate plates or lamellae of each of the metals.

More recent investigations have shown that almost all metals are slightly soluble in each other, and so a more correct diagram of this group of alloys is given here. (Fig. 32.)

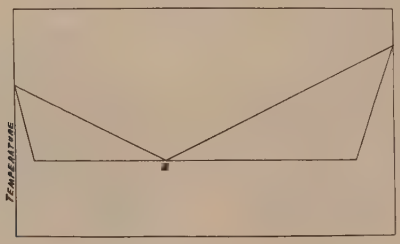


FIG. 32

An equilibrium diagram of alloys whose component metals form a definite compound is shown in Fig. 33.

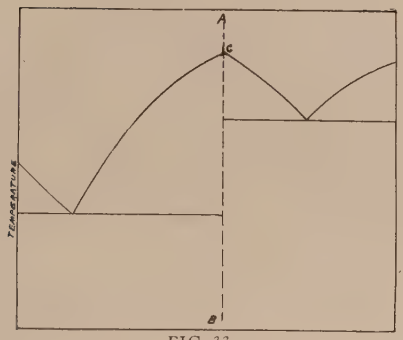


FIG. 33

By dividing this curve (Fig. 33) at the dotted line "AB," it will be seen that the diagram is made up of two curves of the type just described. The explanation of this is that at the point "C" a definite chemical compound of the two metals is formed, and as in the preceding case this acts in the same way as a pure metal forming a eutectic with the pure metals, etc.

If there were no other changes in an alloy except those which take place while the metal is in the process of solidification, the science of metallurgy would be much simplified, but at the same time of very little value because it is upon the very fact that in the more important alloys changes *do* take place after the metal has solidified that their physical properties can be changed and controlled. By changes is meant evolutions of heat on cooling to atmospheric temperature, and the corresponding absorptions of heat on heating, both of which are accompanied by a marked change in the physical properties of the alloy. The points at which these phenomena take place are called critical points, transition points, or transformation points, etc. Obviously, these points indicate some change in the crystals, the atoms, or molecules—in other words, allotropic modifications.[1] As will be described in more

[1] Allotropy is best defined by the example of carbon, which exists in three distinct forms: as the diamond, as graphite, and as amorphous carbon (coke).

detail later, in the case of iron and steel these transformations may be retarded and often suppressed by cooling very quickly from a high temperature. In this way it is possible to retain the metal in the same condition at atmospheric temperature as it existed at the moment when cooling commenced.

COPPER-ZINC ALLOYS

As the same principles hold true for most of the non-

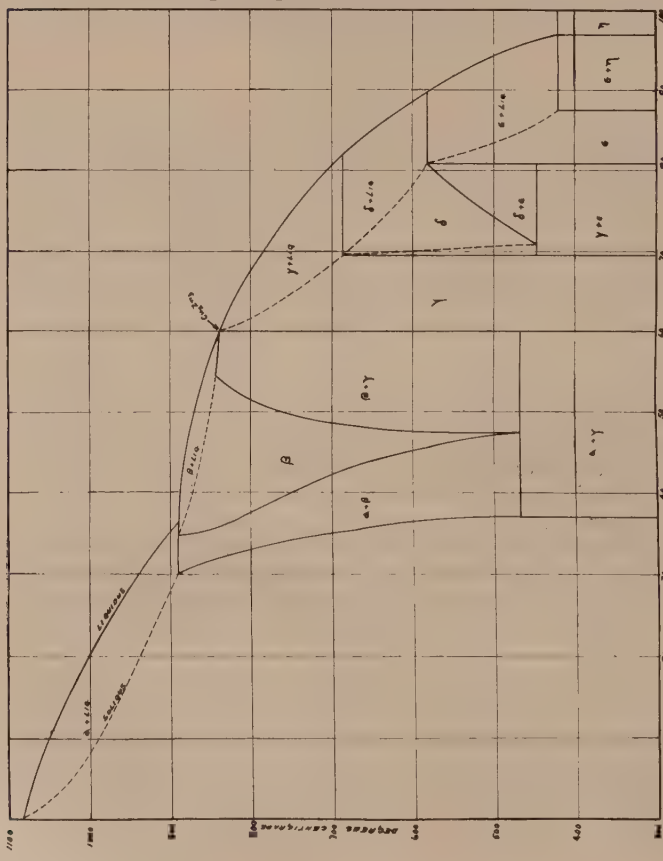


FIG. 34
Equilibrium Diagram of Copper-Zinc Alloys

ferrous alloys used in commercial practice, it will only be necessary to discuss one group of these in order to understand the way in which the whole problem of metallography is attacked.

In Fig. 34[2] is given the complete equilibrium diagram of the series of copper-zinc alloys known as the brasses, an examination of which will show that the shape of the liquidus and solidus curves is of the type indicating the formation of a solid solution, except that in this case there are several solid solutions occurring instead of one. Below the solidus the existence of several different constituents can be noted, known as alpha, beta and gamma, etc., which make the diagram very complex. Fortunately, however, there are practically no commercial alloys containing more than 60% zinc, and so it is only necessary that attention be given to the left hand side of the diagram.

Here there are three solid solutions, alpha, beta and gamma. The exact nature of these solutions is not definitely known, but it is only necessary to know that each have certain physical and structural characteristics which are easily discernible. Alloys consisting of the alpha solution, whether obtained by quenching from a temperature at which this solution exists, or by regulating the percentages of the two metals so that the alpha solution will be retained even when the metal is cold, are strong, malleable and ductile and especially suitable for drawing and rolling. Alloys containing the beta solution are somewhat harder, and when cold are much less malleable and ductile; and these alloys containing the gamma crystals are very low in tensile strength and ductility. The two solutions, alpha and beta, are easily distinguished under the microscope, since beta crystals become darkened by the etching reagents before the others, and also there is a marked difference in the color—the alpha being a reddish yellow and the beta a greenish yellow.

[2] After Hofman.

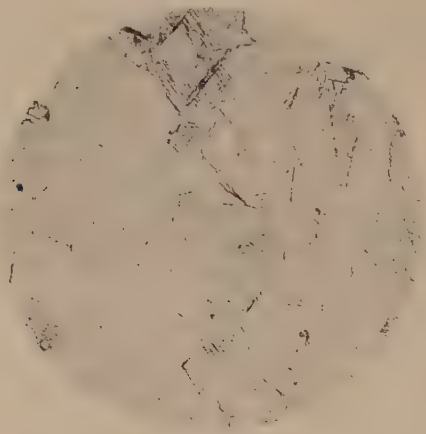


FIG. 35
Alpha Brass Magnified 500 Times

It is obvious, then, that by regulating the amounts of copper and zinc and the temperature to which the alloy is heated and the speed of cooling from that temperature, the most advantageous properties of each of these constituents can be imparted to the metal. The physical properties of brass may be improved also by mechanical working.[1] The addition of other substances to this group of alloys is also of great importance. By this means special physical properties can be imparted to the alloys more suitable for the purposes for which they are to be used.

EFFECT OF OTHER METALS ON THE MICRO-STRUCTURE AND PHYSICAL PROPERTIES OF BRASS

Tin, when present in amounts less than 1.0%, is dissolved in the metal forming a solid solution, but when in excess of this amount, precipitates out as a separate con-

[1] The influence of hot and cold working on the metals is described elsewhere in more detail.

stituent which appears as a light blue under the microscope. This constituent is hard and brittle, and is probably a compound of tin and copper.

Lead is present in the free condition, and appears in small round particles and streaks when examined microscopically. This constituent is usually seen around or between the grains.

Iron, aluminum and manganese, when present in small amounts, are in solid solution and increase the strength and toughness of the brass, as well as making it more resistant to corrosion.

IRON-CARBON ALLOYS

The application of the principles of metallography in connection with non-ferrous metals has been discussed only in a general way, not because it is unimportant, but because of the somewhat greater importance of iron and steel in the industrial world, and also because the metal-

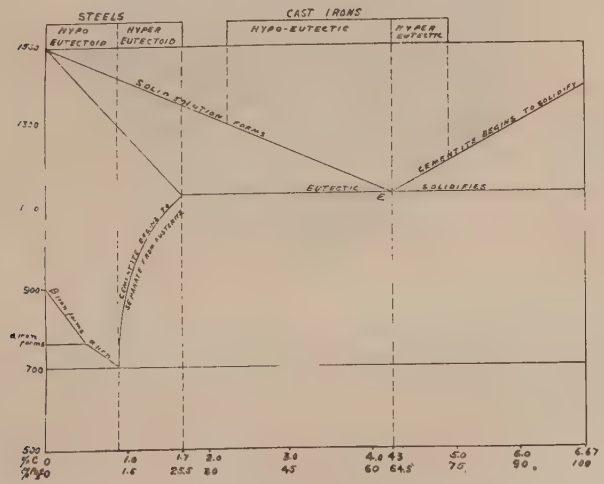


FIG. 36

Equilibrium Diagram of Iron-Carbon Alloys

lography of iron and steel embodies in a greater degree all the principles found in the metallography of the non-ferrous alloys.

As has been pointed out, it is upon a clear understanding of the equilibrium diagrams that the whole knowledge of the subject depends, and so this will be described first in some detail. The equilibrium diagram of the iron-carbon alloys, which include all the steels and cast iron, is shown in Fig. 36[1]. It will be seen on examination that this diagram does not extend from a concentration of 100% iron to 100% carbon. This is because molten iron will not

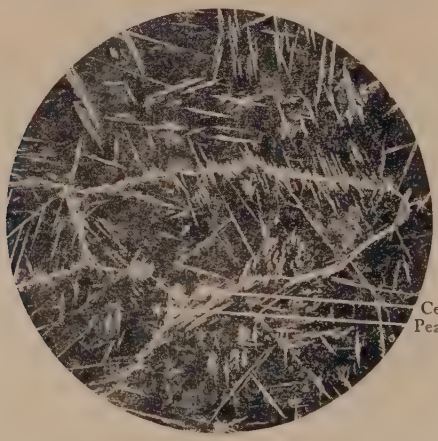


FIG. 37

Micrograph of 1.40% Carbon Steel Showing Cementite and Pearlite X 100

dissolve much more than 5% carbon, and so alloys with a greater percentage cannot be prepared. The diagram is carried to 6.67% carbon, however, because it has been found that carbon does not dissolve in iron as such, but as the carbide of iron (Fe_3C) and this represents 100% of the carbide. The curve, then, resolves into a diagram of a series of alloys of iron and the *carbide* of iron.

[1] After Sauveur.

Steel is iron with varying amounts of carbon, and it is the way in which the carbon is combined with the iron, and the condition of those combinations, which determines the physical properties of the steel. In the case of steel, the carbon, which is in small proportion relatively to the iron,

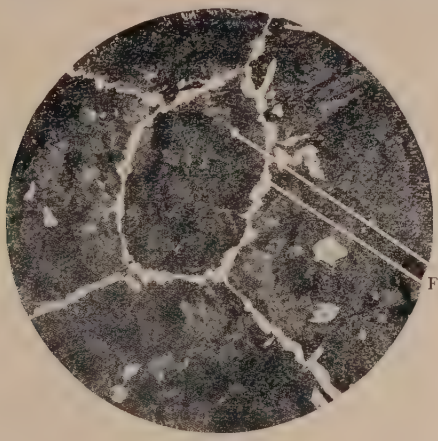


FIG. 38

Micrograph of 0.50% Carbon Steel Showing Pearlite and Ferrite X 100

is in chemical combination with iron, a combination or compound in which the iron and carbon are always in fixed, definite proportions, forming a hard and brittle material which is an iron carbide, and is called cementite; in steels which are richer in carbon there will be, therefore, more cementite than in steels with less. If iron contained about 6.67% of carbon, it would be possible that all the iron and all the carbon could be combined into cementite, but common steels contain very much less carbon than the above-named percentage, and therefore there is always more or less iron which must be left over and not combined with carbon. This left over iron is called ferrite, and is soft and ductile. These two materials are found in steels in the form of crystals and can be readily detected by the microscope in prepared specimens.

Now it would be easy to explain that high carbon steel is harder than low carbon steel if it could simply be said that it is so because there is more cementite or combined iron and carbon in the high carbon steels and less ferrite than in the low carbon steels, and this is true to a certain extent; but the real explanation is much more complex. When two substances of certain kinds are brought together under certain conditions they may dissolve in each other. This is a phenomenon which is commonly known as solution, and liquid solutions are known to everyone; but it is not so generally realized that there can also be solid solutions, and steel under certain conditions of temperature is a solid solution of iron and carbon. There are many cases where two substances will be dissolved in each other at certain temperatures, for example, at the temperatures at which one or both of the substances are liquid; but when the temperature of the solution is lowered and the solidifying or freezing points of the substances are approached the solution no longer takes place, and the two substances separate by crystallizing individually, although these crystals may be so intimately mixed that only by the microscope can the two substances be recognized.

There are many substances, two of which can be dissolved in each other in a wide range of proportions, and form a liquid solution at a certain temperature. Now if the temperature of such a solution is lowered, a point will occur where solidification begins, and this point of temperature depends on the relative proportions of the two substances. If a great number of experiments were made with such a solution, at each experiment the relative proportions of the two substances being, for example, with substances A and B in relative proportions between 100% A and 0% B and 0% A and 100% B, a relative proportion would be found which remained liquid at a temperature lower than any other, and this temperature is always less than the solidifying or freezing temperature of either of the two substances. At this lowest temperature the two substances freeze or solidify simultaneously, and in certain

cases the solidified mass will be found to consist of intimately mixed crystals of each of the substances. The relative proportions of two such substances at which this lowest solidifying point occurs is a definite and constant proportion, and it is called the eutectic of the two substances, and the temperature is called the eutectic point or temperature. When a solution, not of the definite proportion as described, is cooled at some point above the eutectic point solidification of one only of the two substances will begin, namely, the substance which is in greater relative proportion than the eutectic proportion. The solidification of that one substance will continue as the temperature drops, and just so much of that substance will solidify so that when the eutectic temperature is reached, there will be just the eutectic proportion of the two substances remaining in the liquid state, and on further reduction of temperature the whole remainder will solidify together.

These facts apply to associations of iron and carbon, but are complicated by the fact that solutions may be solid as well as liquid, and where in a liquid solution there was change from liquid to the solid state, in solid solutions there will be changes in the condition of the solid state. In observing such phenomena as are described above there is little difficulty where it is a case of changing from a liquid to a solid condition, but where, as in the case of steel, it is a case of a solid solution, the changes taking place are not so manifest, and slow and tedious operations must be performed to find out what actually has taken place.

If a piece of steel, that is, a piece of iron alloyed with a certain amount of carbon, is heated to near its melting point and allowed to cool under conditions which will not interfere with the regularity of the speed of its cooling, and if means are used to note the temperature of the steel at all instants during this cooling, it might be expected that the rate of cooling would be capable of being represented by a regular curve; that is to say, that the temperature of the steel would drop with regularly decreasing acceleration until the steel was cold. But this is not the case, be-

cause it is found that the piece of steel will cool to a certain temperature at a regular speed, but on reaching that temperature the cooling slows down, stops, or it may even be that the temperature increases slightly, although the conditions under which the piece is cooling have not changed in any way. After a period of time, cooling continues again in a uniform manner, until another point is reached, where the same irregularity is again observed. There may be one, two or three such points.

In a similar manner, if a piece of steel is gradually and regularly heated there will occur points in the rising temperature where the steel will not increase in temperature for a period of time, but will remain at a certain temperature, or even become a little less hot for a time, and again continue to heat up regularly. At these temperatures something is evidently happening in the steel which is not caused by the means used to cool or heat the steel. It is also evident that whatever does happen within the piece of steel requires a certain time to take place. The microscope has shown that very important changes actually do take place at those temperatures—changes, in fact, which are in line with the phenomena of solutions which have just been mentioned. The temperatures where there is a change in the rate of absorption, or giving out of heat, are called the critical temperatures of steel.

It may not be out of place here to meditate a little on the enormous importance of what is commonly called heat, in the sense of relative temperature. Relative temperature, or let us roughly call it heat, is a vital factor in nearly every phenomenon known. Human beings, and indeed practically all that we know as life, can exist only within a very small range of temperature, and we become accustomed to think of the inanimate material and objects with which we busy ourselves as being permanently in the condition which we commonly see them, that is, in the condition in which they can exist within the comparatively narrow limits of temperature in which life as we know it develops. But all matter can exist in more than one condi-

tion, this condition depending (though possibly not entirely) on temperature; there may be the solid, liquid and gaseous conditions. This, of course, is very well known, and is daily exhibited in the case of water and a few other common things, but the range of temperature of each condition is so wide in many substances that the practical person only sees and imagines them in the condition possible within the small range of temperature of daily human life. But when, by some artificial means, a material is heated up to a temperature far beyond what we ordinarily are acquainted with (or, on the other hand, cooled down to very low temperatures) changes may take place in that material which alter its physical properties so that it loses all the characteristics which were well known at ordinary temperatures.

Heat, of course, can only be judged relatively, and outside of certain low and high limits which have been experimentally possible up to the present time we do not know what may be the influence of heat on matter, and when it is said that matter can exist in three conditions depending on temperature, it must be understood that this statement only applies within the range of temperature which we know.

These few elementary remarks have been inserted here to show that there should be nothing surprising in the behavior of steel when its temperature is artificially changed.

Pure iron can exist in more than one form according to its temperature. Below the first critical temperature where, it has been remarked, a change seemed to take place, iron is in the condition known as alpha iron. This iron is magnetic and has no power of dissolving carbon. At temperatures above the first critical point, and between other critical points, iron changes successively to beta and to gamma iron. These forms of iron are non-magnetic and have the power of dissolving carbon. We have previously remarked on the distinctions which are made between the alloys of iron and carbon, which are known as various steels, accord-

ing to their carbon content, but in the following remarks we shall not pay much attention to such distinctions.

Let us attempt to follow what occurs in the case of associations of iron and carbon considered as solutions in the same way as described above. The whole range of irons and steels is comprised in combinations of iron with carbon (neglecting, of course, the impurities which are always present to a greater or less extent) in proportions varying from 100% iron and 0 carbon to about 93½% iron and 6½% carbon.

Beginning with the alloy in a molten condition, it will be a liquid solution of iron and the chemical compound of iron and carbon, which is called cementite. When such a hot solution is allowed to cool solidification will begin to take place at successively lower temperatures as the proportion of carbon to iron increases, and so on until the eutectic point is reached, when all will become solid, as in the case described above. This eutectic point occurs when it is an alloy of 95.7% iron and 4.3% carbon. Solidification of alloys having more than 4.3% carbon will begin at higher temperatures.

Now the solid matter which begins to form in cooling alloys having less carbon than 4.3% is a solid solution of this cementite in gamma iron, to which the name of austenite has been given. In alloys containing more than 4.3% of carbon, the first matter to solidify is cementite alone. At the eutectic temperature solidification of the eutectic alloy which is austenite and cementite takes place. For any alloy, for a certain range of temperatures below the eutectic point the solid (but still hot) material will be (1) austenite and eutectic austenite-cementite alloy; (2) eutectic austenite-cementite alloy; (3) cementite and eutectic austenite-cementite alloy, respectively, according as the alloy had less, just the right amount or more carbon than the eutectic proportion.

On following the cooling of this solid solution, other changes take place at the critical temperatures, the critical

temperatures and the changes depending on the proportion of carbon in the alloy. The solid solution acts in a similar manner to the liquid solution. The solid solution consists of cementite dissolved in iron and the eutectic mixture or alloy, and it, too, has a eutectic, which in the case of the solid solution is called eutectoid. At the lower critical temperature the solid solution changes into ferrite (or pure iron), and the eutectoid ferrite and cementite, or cementite (or iron carbide) and the eutectoid ferrite and cementite according to the proportions present. This final eutectoid of cementite and ferrite is called pearlite, and under the microscope it appears as fine laminated layers of cementite and ferrite crystals, and has a composition of about 0.89% of carbon. There are many other transition stages, and numbers of names have been given to forms of iron and carbon between austenite and pearlite, and in alloys containing high carbon percentages, the carbon of the cementite may disunite with the iron and appear as graphite or pure carbon, which in fact occurs in gray cast iron.

The above description will give a rudimentary idea of the changes occurring in the constitution of iron and carbon alloys, according to the proportion of carbon present, as they are allowed to cool from a molten liquid state down to atmospheric temperatures, and it may be said that these changes take place in reverse order as an iron carbon alloy is heated up from atmospheric to melting temperature. It must be particularly understood that this cooling must be slow, in order that the time be sufficient to allow the changes to take place completely. But if the rate of cooling is so hastened that insufficient time is given, the changes will be more or less arrested, and a material can be obtained at atmospheric temperature having a very different constitution and physical properties from those obtained under natural conditions. Thus it is that by heating and rapidly quenching and possibly again heating, the constitution and hence the physical properties of steels can be altered.

In the above account we have discussed solidification, which is the formation of crystals of the various sub-

stances. A single crystal does not generally possess uniform physical properties in all directions, and hence it is desirable to obtain a material which will be made up of a great number of small uniform crystals, arranged in all possible directions, rather than a material made up of a few large crystals. Crystals are formed by growth, and for the production of large crystals considerable time is required. A rapidly cooled steel will have smaller crystals than one allowed to cool more slowly. There is another way, however, of breaking up large crystals, and that is by hammering, rolling or squeezing during the range of temperature when the changes are taking place in the solid solution, at the time in fact when the crystals of the various constituents are forming. This is one of the objects of forging.

We have disregarded not only the impurities which are always present in iron and steels, but also have not considered the other elements which are intentionally added to steel, such as manganese, nickel, chromium, etc. All of these have an effect, but do not prevent the general occurrence of the phenomena as described. They have, however, an important influence on the nature of the changes, and in certain cases form compounds with carbon themselves.

By comparing the shapes of the curves of the liquidus and solidus in Fig. 36 with those in Figs. 27 and 28, it may be seen that in the region containing from a trace to about 1.7% carbon and embracing all the steels, the alloys solidify as solid solutions; and in the regions containing from about 2% carbon to about 5% carbon and in which fall all the cast iron, a eutectic is formed.[1] Austenite[2] as the solid solution is called, will dissolve, then the carbide of iron, until the total carbon content reaches 1.7%, at which

[1] The division between the steel series and the cast-iron series is purely for convenience, but the fact that there are very few commercial products containing between 1.7% and 2.5% carbon make it a particularly convenient one.

[2] Henry C. Sorby, a noted petrographist of Sheffield, Eng., may be considered to have laid the foundation of the microscopical examination of metals. He regarded steel as a kind of igneous rock and it is from this mineralogical standpoint that most of the names of the microscopical transition constituents of iron and steel end in "ite."—sorbite, pearlite, austenite, martensite, etc. In most cases, the first portion of the word is derived from the personal name of a pioneer metallurgist.

percentage the solid solution becomes saturated (in exactly the same manner as liquid solutions), and when the total carbon is increased the austenite, unable to hold any more of the carbide in solid solution, precipitates out of the solid solution as such and the carbide, with the iron that is left, goes to make up the eutectic. This process continues until the point "E" in the diagram is reached, where the alloy solidifies as 100% eutectic. In the same manner to the right of the eutectic point in the diagram the excess constituent is the carbide of iron.

But here again, as in the case of the brasses previously described, there are transformations which take place after the metal has solidified, and it is due to the existence of these points that iron and steel objects of the same chemical composition can be given such a wide variety of physical properties.

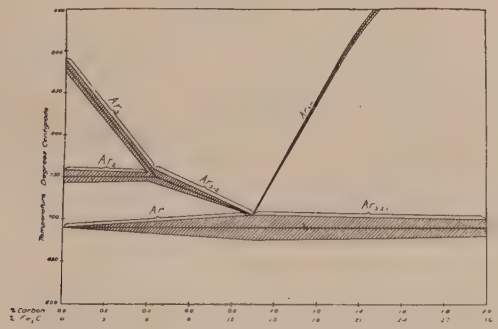


FIG. 39

Diagram Showing Critical Points of Steel

As may be seen in the diagram above,[1] showing the critical points of steel (on a larger scale than is shown in the complete iron-carbon diagram), pure iron has two critical points after the metal has solidified,[2] one occurring at about 900° C. (1652° F.), and another at about 760° C. (1400° F.). This indicates that iron exists in

[1] After Sauveur.

[2] The shaded portions indicate the intensity of the critical points.

three allotropic forms—called alpha, beta and gamma.[1] The point marking the division between gamma and beta iron is known as the Ar_3 point,[2] and the point marking the division between the beta and alpha iron is known as the Ar_2 point [3]. As soon as there is any carbon present another point appears at about 690° C. (1274° F.), known as the Ar_1 point. The three points then continue until there is a little over 0.4% carbon, when the two upper points merge, forming a single point, which is called the $Ar_{3.2}$ point, which in turn merges at 0.85% carbon forming the $Ar_{3.2.1}$ point. From 0.85% carbon to about 2.0% carbon there are two points—the new point being known as the Ar_{cm} point.

It may be seen that the shape of these curves closely resembles that shown in the diagram illustrating the general type of a curve representing the formation of a eutectic, from which it would follow that a eutectic would be formed at about 0.85% carbon. This is actually what happens, except that since solid solutions are being dealt with instead of liquid solutions, the resultant laminated structure is called the *eutectoid*.[4]

The following four photo-micrographs illustrate the structure of steel in the cast condition containing varying amounts of carbon as noted.

[1] There is much controversy as to the presence of more than two allotropic forms. Some authorities contend that beta iron does not exist.

[2] The "r" in "Ar_3," etc., is the first letter of the French word refroidissement, which means cooling. The points obtained on heating are Ac_3, etc., the "c" being the first letter of the French word chauffage. The transformation points occur at a somewhat lower temperature on cooling than on heating. This phenomenon is called "lag."

[3] The A_2 (i. e., Ar_2 and Ac_2) point is sometimes called the magnetic transformation because at this point the metal on heating loses its magnetic properties and gains them on cooling.

[4] Steel containing less carbon than the eutectoid ratio is called hypo-eutectoid, and steel containing more carbon than eutectoid ratio is called hyper-eutectoid.

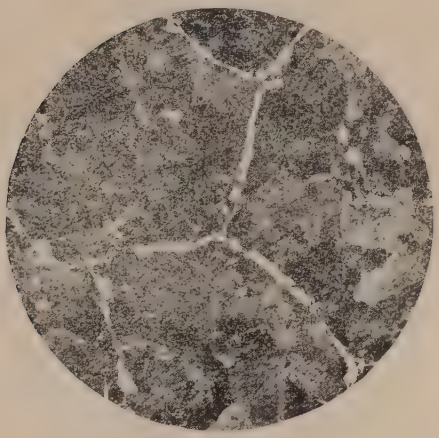


FIG. 40

Photo-micrograph of .40% Carbon Steel as Cast. Magnified 100 Times. Etched in a 4% Solution of Nitric Acid and Alcohol

The black constituent in the above photo-micrograph is the eutectoid of iron and the carbide of iron, called pearlite because of its resemblance in color with the naked eye to mother-of-pearl; and the white constituent is made up of the crystals of iron (in excess of the eutectoid ratio) called ferrite. Pearlite is relatively strong, hard and ductile; while ferrite is weak, soft and ductile.

Pearlite is a mechanical mixture of pure iron and cementite, usually existing in thin plates of the carbide and ferrite.

Fig. 41 shows the structure of a piece of steel, the structure of which is all pearlite, and the picture in Fig. 42 shows the same piece of steel taken under a higher magnification, which brings out the characteristic laminations. In this picture the white constituent is the carbide of iron called cementite and the dark constituent is the ferrite. (The reason the ferrite is dark here is because it

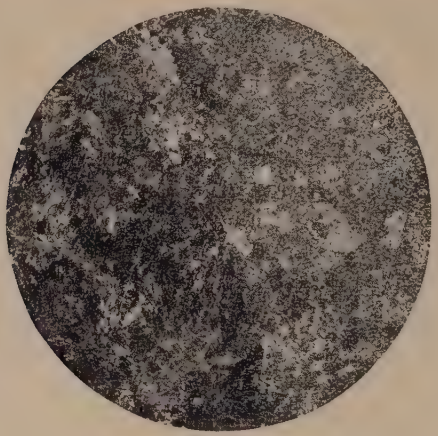


FIG. 41
EUTECTOID STEEL
Photo-micrograph of 0.85% Carbon Steel as cast. Magnified 100 times.
Etched in a 4% Solution of Nitric Acid and Alcohol

FIG. 42
EUTECTOID STEEL
Photo-micrograph of 0.85% Carbon Steel. Magnified 500 times.
Etched in a 4% Solution of Nitric Acid and Alcohol

is more soluble in the etching reagent than the hard cementite, and is consequently thrown in shadow.) Cementite is very hard, strong, but very brittle.

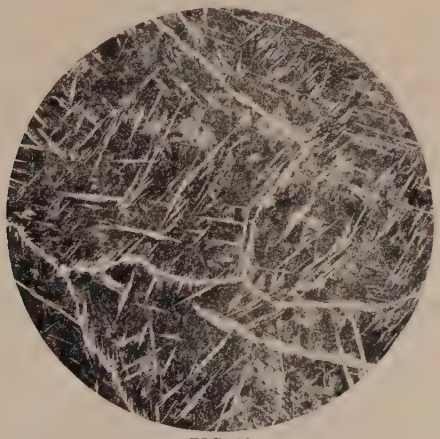


FIG. 43

Photo-micrograph of 1.25% Carbon Steel as Cast. Magnified 100 times. Etched in a 4% Solution of Nitric Acid and Alcohol

This photo-micrograph shows the structure of high carbon steel as cast. The excess constituent is now the cementite, the needle-like forms in the grains and the white substance at the grain boundaries. The dark constituent is, of course, the pearlite, or eutectoid.

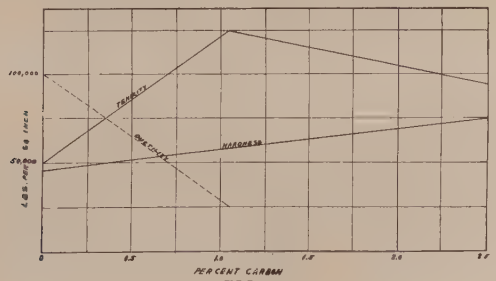


FIG. 44

CAST IRON

As has already been mentioned, the group of iron-carbon alloys containing approximately between 2.5% and 5.5% carbon is called the cast iron series. It may be seen from the equilibrium diagram that when cast iron solidifies the carbon is in the combined condition, *i. e.*, the carbide of iron which is partly free and partly in solid solution. This carbide is, however, an unstable compound, and at high temperatures is readily decomposed into graphite (one of the allotropic modifications of carbon) and iron. The result of this decomposition is that when the iron has cooled to atmospheric temperature, part of the carbon is present as the carbide and part as free carbon in the form of graphite. Certain impurities as well as the rate of cooling influence this breaking up of the carbide to a very

FIG. 45
Grey Cast Iron

marked degree, *e. g.*, silicon and slow cooling promote the formation of graphite, and manganese tends to keep the carbon in the combined condition. The photo-micrograph above (Fig. 45), showing the structure of cast iron clearly shows why this metal is weak, lacks ductility and

cannot be forged or hammered. The flakes of graphite (a soft and weak substance) break up the continuity of the mass, as shown by the dark streaks in the photograph, making it very brittle and low in tensile strength.

If there is very little silicon and a relatively high percentage of manganese present, the carbon, in spite of a fast rate of cooling, will remain in the combined condition and the resultant product is called white cast iron (so called from the appearance of its fracture as contrasted with that of gray cast iron). This metal, too brittle to

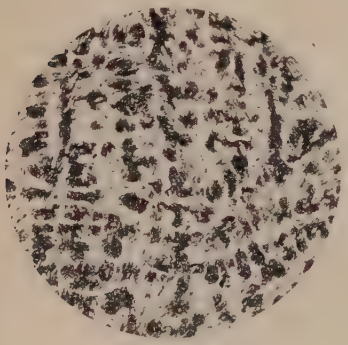


FIG. 46
White Cast Iron

FIG. 47
White Cast Iron after Malleabilizing Treatment

be used for many purposes, is the basis of the malleabilizing process. Castings made of white cast iron are placed in large containers together with a suitable packing material and heated to a high temperature (but below the melting point of the metal). The carbide of iron breaks up into graphite and iron, but in this case the graphite takes the form of rounded particles instead of flakes. The result is, obviously, a metal which is a great deal stronger and more resistant to shock than gray cast iron. The name malleable is, clearly, a misnomer, because castings made of this metal cannot be forged or hammered. The photo-micrographs (Figs. 46 and 47)

show the structure of white cast iron before and after the malleabilizing treatment (magnification 100 diameters).

INFLUENCE OF MECHANICAL WORK ON THE MICRO-STRUCTURE OF ALLOYS, WITH PARTICULAR REFERENCE TO IRON AND STEEL

Mechanical work may be divided into two classes, namely, hot work and cold work. These may be conveniently defined as work performed *above* the critical range, and as work performed *below* the critical range.

HOT WORK

The purpose of hot work, such as forging, hammering, etc., is to shape the metal into useful articles and also decrease the size of the grains, which greatly improves the

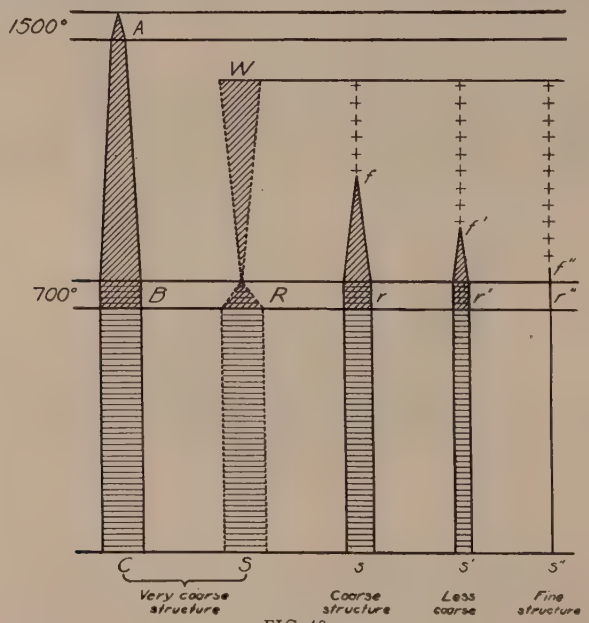


FIG. 48
Influence of Hot Work on Structure of Steel

physical properties. The diagram[1] (Fig. 48) clearly depicts the influence of hot work on the structure of steel. While this is not strictly true for alloys other than steel, the principles involved are very similar.

As the steel ingot solidifies at A, or is reheated (after the ingot has cooled) to W, crystalline grains of the solid solution of iron and the carbide of iron form and gradually increase in size until the critical range of the metal is reached. This growth requires slow and undisturbed cooling. Clearly, then, in order to produce the minimum amount of grain growth (the smaller the grains the stronger the metal) work must be stopped just above the critical range. As shown in the diagram, if work is stopped at f or f′ a larger grain growth will result than if the work is stopped at f″.

FIG. 49

Photo-micrograph Showing the Structure of Hot-Worked 0.30% Carbon Steel. Magnified 100 Times. Etched with a 4% Solution of Nitric Acid in Alcohol

The three photo-micrographs (Figs. 49, 50 and 51) show the structure of hot worked hypo-eutectoid, eutectoid, and hyper-eutectoid steel respectively.

[1] After Sauveur.

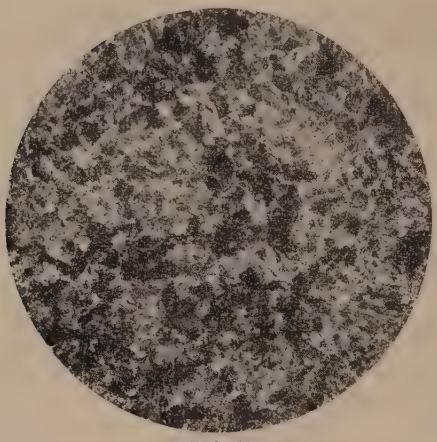


FIG. 50
Photo-micrograph Showing the Structure of Hot-Worked Eutectoid Steel.
Magnified 100 Times. Etched with a 4% Solution
of Nitric Acid and Alcohol

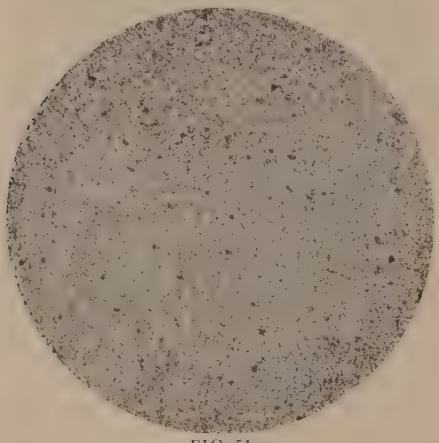


FIG. 51
Photo-micrograph Showing the Structure of Hot-Worked 1.25% Carbon Steel
Magnified 100 Times. Etched with a 4% Solution
of Nitric Acid and Alcohol

COLD WORK

Whereas steel above the critical range is composed of a solid solution, below the transformation range it is composed of an aggregate of pearlite and ferrite (or cementite).[1] Cold work, then, simply distorts the grains of pearlite and ferrite into elongated masses. Cold work increases the elastic limit, tensile strength and hardness, while it decreases the ductility as represented by the elongation and reduction of area. Micrograph (Fig. 52) shows the structure of cold worked steel.

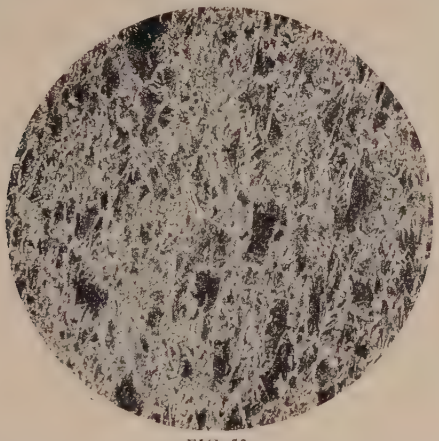


FIG. 52

Photo-micrograph Showing the Structure Produced by Cold Work in a Steel Containing about .30% Carbon. Magnified 100 Times. Etched with a 4% Solution of Nitric Acid and Alcohol

HEAT TREATMENT OF STEEL

Heat treatment, as defined by Tiemann, is, "the change, or the series of changes, in temperature; also the rate of change from one temperature to another, brought about to secure certain desired conditions or properties in a metal or alloy." Heat treatment in general may be conveniently divided into three classes: (1) Softening Treat-

[1] High carbon steel on account of its hardness is seldom cold worked.

ment; (2) Hardening Treatment; and (3) Strengthening Treatment.

By ascertaining the chemical composition of a steel, its critical temperatures are then known. It then may be heated to a temperature at which the constituents acquire a certain form. It is then a matter of cooling at such a speed that these constituents may be more or less retained permanently at atmospheric temperature. Again the operation of tempering or drawing consists in causing a partial return to more natural or normal conditions. The length of time during which the piece in question is maintained at certain temperatures will also have influence on the crystal growth and will be reflected in the final size of grain of the material.

The true explanation of the hardening properties of steels is still a subject of discussion, and many and even conflicting theories have been advanced by the leading authorities; we can only say here that hardness appears to depend on the form which the carbon assumes in its union with iron when there has been rapid cooling from a temperature above the critical point. We have seen that a piece of normal steel (it must be borne in mind that in speaking of steel it is intended to indicate an alloy of iron with from 0.10% to about 1.75% carbon, and possibly small amounts of one or more other metals, such as manganese, nickel, chromium, vanadium, molybdenum, etc., as well as the real impurities, sulphur, phosphorus and silicon which are always present) below the first critical temperature, consists chiefly of ferrite and cementite, in separate, though perhaps very much interlocked, crystals. When it is heated above the critical point the ferrite changes to what may be beta or gamma iron, and at the same time dissolves the cementite as a solid solution, this solid solution being called austenite. Now when this hot austenite is cooled quickly it does not have time to be resolved into ferrite and cementite, but if cooled quickly enough will remain in the austenitic state (and it may be here remarked that this condition can be facilitated if certain amounts of manganese or nickel are present). The

natural rapidity of the change, however, is considerable, and in usual quenching operations the austenite has time to make a partial change, assuming thereby intermediate forms which are called martensite, troostite, sorbite and other names. Of these, martensite is the hardest. The tempering operation which may follow a rapid cooling or quench allows the change to go a little further, and at the same time allows of an adjustment of the internal structure, and relief of strains set up by unequal contraction in cooling.

In order to obtain maximum softness a very slow rate of cooling through the range is used which produces pearlite. The structure of pearlite has already been explained.

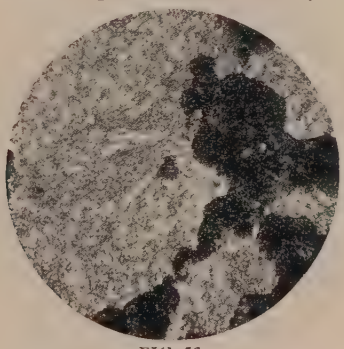


FIG. 53
Martensite—Light. Troostite—Dark.
Photo-micrograph of 1.25% Carbon Steel Quenched in Water from above the critical range. Magnified 100 Times. Etched with 4% Solution of Nitric Acid and Alcohol

To produce maximum hardness, the steel should be in the martensitic condition. This is obtained by cooling through the range at a fast rate, *i. e.,* by quenching in water or oil.[2]

Troostite is often present along with martensite in hardened steel and possesses similar physical properties.

The photo-micrograph (Fig. 53) shows the structure of martensite and troostite.

[2] Theoretically, austenite should result from this treatment, but in plain carbon steels partial transformation always takes place.

If maximum strength, combined with maximum ductility, is desired, the steel should be in the sorbitic condition. Sorbite can be obtained by cooling through the range at the proper speed, but is usually obtained by a process called tempering, an operation which is always preceded by hardening. The hardening of steel may be compared to a spring which has been tightly coiled, *i. e.,* it is in an unstable condition. By reheating the steel to a temperature below the transformation range, "the spring becomes partially released," and the steel returns to a more

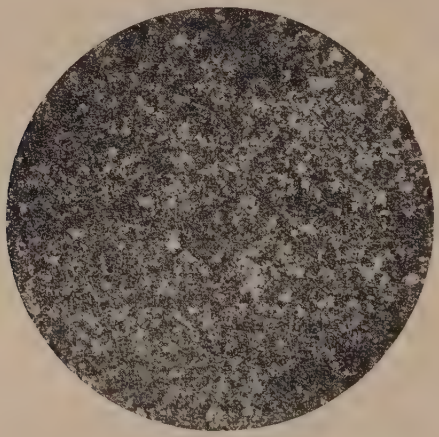


FIG. 54

Photo-micrograph of 0.75% Carbon Steel quenched in Oil from above its critical range and reheated to about 525° C. (977° F.) Magnified 100 Times. Etched in a 4% Solution of Nitric Acid and Alcohol

stable condition. The temperature to produce sorbite varies according to the composition, but for plain carbon steels is in the vicinity of 525° C. (977° F.).[1] The photo-micrograph (Fig. 54) shows the structure of sorbite.

CASE HARDENING

Of the many special processes used in connection with

[1] Troostite may be formed in this way by reheating or "drawing" to a lower temperature.

heat treating and preparing steel for useful purposes, Case Hardening is perhaps the most important and most widely used. As the name implies, a hard case may be produced on the surface of a soft steel, in order to make it more resistant to wear. This process is of special value in ball bearings, armor plate, or on any machine part which requires a tough steel and at the same time a very hard exterior. Case hardening is made possible by the ability of iron to absorb carbon at a high temperature (but below the melting point). In short, a high carbon content is obtained on the outside of the piece.

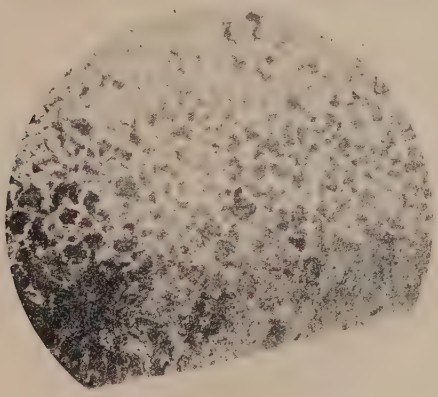


FIG. 55
Photo-micrograph of a Specimen of Case Hardened Steel. Magnified 100 Times. Etched with a 4% Solution of Nitric Acid and Alcohol

INFLUENCE OF SOME IMPURITIES ON STEEL

Manganese has a greater affinity for sulphur than iron has, and, therefore, if any sulphur is present manganese sulphide is formed. This, under the microscope, appears in castings as small round areas, pale gray in color, and in forgings as elongated streaks of the same color. If there

is any manganese left after the sulphide has formed, the carbide of manganese (Mn_3C) is produced, which forms a solid solution with the iron. If manganese is present in large percentages (*e. g.,* over 12.0%) it prevents the transformation changes from taking place until below that of atmospheric temperature, thus causing the steel to be in the austenitic condition when cold. Steel in this condition is very resistant to abrasion.

The effect of sulphur upon the ductility and tenacity of steel, at least up to 0.10% of sulphur, is very slight and may be disregarded. It has been stated that it increases corrodibility of the steel. Its most marked effects are met with in hot working; that is, in rolling or forging the steel, and believed generally to be harmful. If it exists as iron sulphide, then it is capable of doing great harm in hot working, but when in the form of manganese sulphide its harmful effects are negligible. The reason for the harmful effects of the iron sulphide and the harmless effect of the manganese sulphide is, according to most authorities, due to the fact that the iron sulphide forms at the surface of the crystals, *i. e.,* exists in the grain boundaries, and as iron sulphide is fusible at a relatively low temperature (red heat), the crystal boundaries by becoming fluid interrupt the continuity of the mass and render the metal hot short. Manganese sulphide, however, instead of forming envelopes around the crystals, collects or segregates into globules at a temperature close to that of the metal on solidifying, upon which the main body of the metal then contracts. Manganese sulphide has a much higher melting point than iron sulphide, and, therefore, does not melt at the rolling or forging temperatures, but becomes merely plastic with the steel.

In this condition, under the rolling action, it forms fibres, which, if in sufficient quantity, give the steel when fractured longitudinally an appearance similar to wrought iron. Since manganese has a greater affinity than iron for sulphur, it becomes only necessary to add sufficient manganese to prevent the formation of iron sulphide. In

order to get the full benefit of the manganese as a deoxidizer, and as a treatment for sulphide of iron, it becomes necessary to add about three times the theoretical amount of manganese.

The fibrous structure of the high sulphur steel is used in the manufacture of free cutting steel, such as is known as screw stock. In this class of steel, sulphur is deliberately added to obtain the fibrous structure which is undoubtedly the cause of its free cutting properties.

At the present time the tendency is to extend the limits of sulphur, providing it is accompanied by a sufficient amount of manganese. The work done by both British and American investigators shows that there is practically no difference in the rolling, forging or welding qualities, nor in the physical properties of low carbon steel containing from .030% to 0.120% sulphur.

Phosphorus is present as the phosphide of iron (Fe_3P), which goes into solid solution. In cast irons, due to the large amount of carbon present, a eutectic of iron and the phosphide of iron is formed. Iron phosphide makes the steel very brittle, especially when the steel is cold.

Silicon is present as FeSi, and goes into solid solution with the iron. When in small amounts, silicon produces no marked influence on the physical properties.

Such elements as nickel and chromium, etc., form solutions with iron and tend to improve the physical properties of the metal. They are usually added in amounts less than 5.0% and increase the hardness without decreasing the ductility.

A FEW EXAMPLES OF THE APPLICATION OF THE MICROSCOPE IN THE IRON AND STEEL INDUSTRY

The examination of iron and steel by means of the microscope makes it possible to regulate and control the heat treatment and other special processes used in the industry with a greater degree of certainty than by any other method. A few examples of failures, which can be ascribed to faulty heat treatment and conditions in the

metal caused by imperfect manipulation during the special processes as detected by the microscope, will serve to illustrate this.

An automobile shock absorber spring (coil type) which had failed in service was recently received by our laboratory. The spring (measuring .34 inches in cross section) showed no surface cracks or marks. The chemical analysis showed the steel to be of about eutectoid composition and of good quality. Longitudinal and transverse specimens were cut from the spring and prepared for microscopical examination. As may be seen from the photo-micrographs

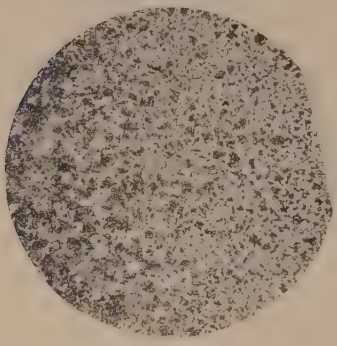


FIG. 56

Photo-micrograph of edge of specimen, showing decarbonized edge. Etched in a 4% Solution of Nitric Acid and Alcohol.

Magnification—100 diameters

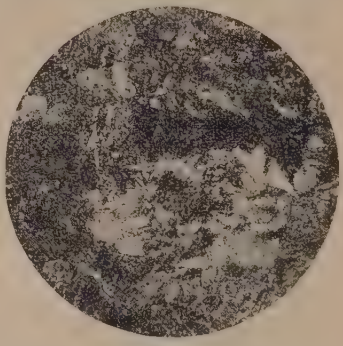


FIG. 57

Photo-micrograph taken near the center of the specimen, showing well developed lamellar pearlite. Etched with a 4% Solution of Nitric Acid and Alcohol.

Magnification—100 diameters

(Figs. 56 and 57), the outside of the piece has been decarbonized to a depth of about 1/32 of an inch, and also well developed lamellar pearlite has formed towards the center of the spring. From the foregoing, it would seem that the cause of failure was due to the spring having received improper heat treatment.

In the first place, it would seem that the necessary precautions were not taken to keep the spring in a neutral or reducing atmosphere while undergoing heat treatment. In

the second place, the presence of well developed lamellar pearlite indicates that either the temperature to which the steel was heated for hardening was not high enough, or that too slow a rate of cooling was employed. This latter supposition, however, taking into account the size of the cross section of the metal, would be very unlikely to occur, as the spring was probably quenched in oil.

Another example of the value of the microscope in detecting the cause of failures may be seen in the photo-micrographs (Figs. 58 and 59) of a casting which broke in service. The photo-micrograph shown in Fig. 58 was taken

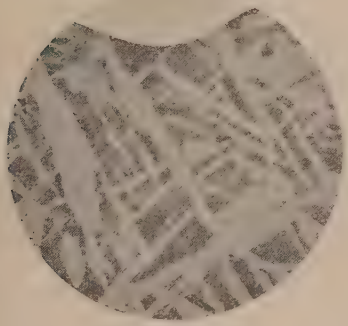


FIG. 58

Photo-micrograph taken at edge of fracture. Etched in a 4% Solution of Nitric Acid and Alcohol.

Magnification—100 diameters

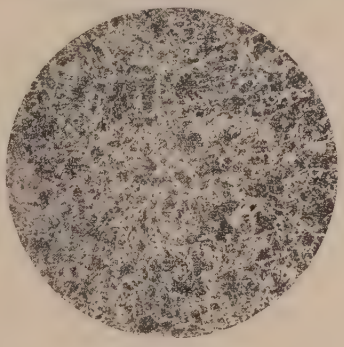


FIG. 59

Photo-micrograph of the same steel properly heat treated. Etched in a 4% Solution of Nitric Acid and Alcohol.

Magnification—100 diameters

at the edge of the fracture and shows typical Widmanstättian structure. Steel in this condition is weak and brittle. If the steel had been heat treated before being used, the casting probably would not have failed. Fig. 59 shows the same steel properly annealed.

The operation of malleabilizing can be carefully controlled with the aid of the microscope. Fig. 60 shows partially malleabilized cast iron, which is weak and brittle as compared to properly malleabilized iron shown in Fig. 61.

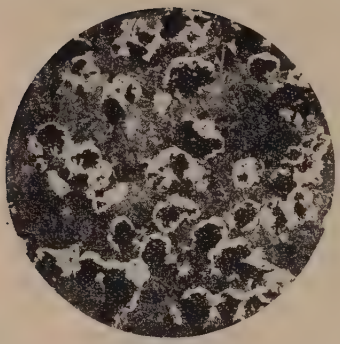


FIG. 60

Photo-micrograph of partially malleabilized white cast iron. Etched in a 4% Solution of Nitric Acid and Alcohol.

Magnified 100 diameters

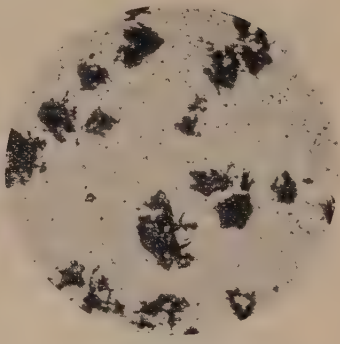


FIG. 61

Photo-micrograph of fully malleabilized white cast iron. Etched in a 4% Solution of Nitric Acid and Alcohol.

Magnified 100 diameters

CHAPTER XI

CLASSIFICATION OF STEEL

Steels are commonly divided into two classes, straight or plain carbon and special or alloy steels.

The former differ from the latter in that they are made up almost entirely of iron, together with more or less iron carbide, and contain small amounts of such elements as manganese, sulphur, phosphorus and silicon, while the special steels have in addition to the above, appreciable percentages of nickel, chromium, vanadium, tungsten, etc.

The carbon steels constitute the ordinary grades of machine steel, structural steel and standard tool steels. They are graded according to their carbon content, roughly as follows:

Very low carbon steel, less than .10% carbon, is known as very mild, or extra mild steel, very soft or dead soft steel.

Low carbon steel, carbon .10% to .25%, is known as mild steel, case hardening steel or simply as low carbon steel.

Medium carbon steel, .25% to .60%, is known as high carbon machine steel or medium carbon steel.

Carbon from .60% to 1.50% is known as tool steels; the range .80% to 1.00% being usually held for ordinary tools, while some of the extra hard tool steels for special purposes contain over 1.25%.

This classification is somewhat arbitrary, as there are no sharp lines in the carbon percentages of separation universally recognized between the various grades.

Carbon steels are used wherever their properties will meet imposed conditions satisfactorily, but when special requirements of strength, toughness, etc., must be met, it

is necessary to improve the properties of the carbon steel by the addition of certain elements.

Practically all carbon steels contain silicon and manganese according to specification, but in such small amounts that they have no special effect on the general physical properties of the steel. When increased, however, to certain percentages, both silicon and manganese produce steels which have entirely different properties from a corresponding straight carbon steel.

It is, therefore, evident that there will be certain percentages of these elements which render it difficult to classify the steel as alloy or plain carbon. This is merely of academic interest, since the regular limits of silicon and manganese for carbon steels are well known and any decided increase would put the steel in the special or alloy class.

There are certain well known and widely used alloy steels of four general classes:

Chrome steels
Nickel steels
Chrome-nickel steels
Chrome-vanadium steels

In addition to these we have the following less used steels:

Manganese
Silicon-manganese
High speed steels of many variations
Vanadium
Molybdenum

The chromium steels can be subdivided according to the percentage of chromium. Since chromium forms a carbide with carbon, it has an influence on the hardness, due to two causes: First, to mineral hardness imparted by the very hard chromium carbides; and, second, to the fact that it retards the decomposition of the austenite and thus permits of the formation of a deeper martensite on quenching. Chromium in itself will not harden steel without the presence of carbon, since it is the carbide of chromium which exerts the above noted increase in hardness.

Chromium steels are characterized by fine grain, when properly treated, which tends to make the steel very tough. This chromium increases the tensile strength and elastic limit without a noticeable loss in ductility.

Low chromium steels, carbon .9%, chromium .50%-.75%, are much used for chisels, hammers, axes, etc.

Chromium steels 1.00% carbon, 1.25% chromium, are much used for ball bearings. This steel produces balls and races which have wonderful strength, and which with an oil quench become extremely hard; chromium up to 2.00% is used in rolls for cold rolling, while from 8% to 15.00% in steel forms a product which is resistant to most forms of corrosion, and is known as "stainless" steel. It is also used for gasoline motor exhaust valves.

Nickel is found in the various "nickel" steels from 2% to 40%, which is a wider field than is covered by any other alloying element. When less than 2% is added the improvement obtained is very slight.

For structural parts, such as gun forgings, engine and automotive forgings, bridges, etc., nickel is added from 2% to 5%, depending on the properties desired.

Heat treatment is necessary to obtain the maximum results, and the nickel steels respond well to heat treatment.

Nickel does not combine with carbon to form a carbide, but alloys with the ferrite itself.

By alloying both nickel and chromium with the plain carbon steel we get a steel which is tough and ductile from the nickel, and increased mineral hardness of cementite and pearlite from the chromium. This combination results in a steel which has most valuable properties, and which is very satisfactory for parts which must be heat treated to develop great toughness, fatigue, and wear-resisting properties.

There are three standard types of chrome-nickel: low chrome nickel, containing about 1.5% nickel and .60% chromium; medium chrome nickel, containing about 2.5%

nickel and 1.00% chromium; and high chrome nickel, containing 3.50% nickel and 1.5% chromium.

Chrome-nickel steel is much used for automobile parts, such as connecting rods, axles, gears and crankshafts. It is used extensively as a die block steel, and also in the manufacture of armor plate.

Chrome-vanadium steel has become one of the best recognized steels of recent years. These steels have physical properties similar to the chrome-nickel steels, except that their contraction of area is a trifle greater for a given elastic limit. They are supposed to be more easily machined than the chrome nickel and more free from surface defects.

Chrome-vanadium steel of about .30% carbon, 1% chromium and .20% vanadium, is extensively used for structural parts requiring greatest toughness and shock-resisting qualities, and when the analysis is .50% carbon, 1% chromium and .20% vanadium, it is used principally for spring and gear stock and produces a superior product.

Manganese steels containing 12% to 14% of manganese are air hardening, and when quenched from 1800° F. retain the austenitic structure which is exceedingly resistant to wear. It is used for parts which are subject to heavy abrasion, such as switch points, dredge bucket teeth, etc.

Silico-manganese steels are used extensively for leaf springs for railroad and automotive work. This steel is generally made in the open hearth, and is somewhat cheaper than the chrome-vanadium. It contains about 2% silicon and .60% to .80% manganese, in addition to .50%-.60% carbon.

Steels known as high speed tool steels generally conform to a standard analysis: Carbon .60% to .80%, chromium 3.50% to 4.00%, tungsten 12.00% to 18.00%, vanadium .75% to 1.50%. This analysis, when properly worked out, gives a good high speed steel; other factors, such as proper reduction, annealing and heating, being very important.

Straight vanadium steel is used generally for steam hammer pistons, etc., as it is superior to plain carbon steel because of the extra toughness imparted by the greater grain refinement resulting from the addition of vanadium.

Tool steels are also classified into two classes: oil hardening and water hardening steels.

Tool steel should be checked before use if it is to be made into important or expensive tools, the important point in the checking of such steel, being to remember that poorly annealed tool steel will, especially on work which has many corners, result in very high losses, due to breakage in hardening.

These losses can be reduced to a negligible amount if the tool steel is very carefully annealed, and when buying tool steel this point should be carefully checked.

Properly annealed tool steel should show at 500 diameters, all the cementite completely spheroidized.

Evidence of lamellar pearlite indicates a poorly annealed specimen and steel of this structure should not be used where tool breakage would be costly.

A properly annealed tool steel will show not only a completely spheroidized cementite under the microscope, but will show when hardened and fractured, a smooth undulating break, with no indication of granular structure. This is a most important test and when the inspector has had a little experience, a microsection is really unnecessary.

It must be remembered that care should be taken in heating such samples that the temperature is correct, as too low a temperature will not develop the structure desired, and too high a temperature will coarsen the grain.

In thick test pieces the structure near the surface should be checked and the central structure disregarded due to the transitional structure developed by the impossibility of the quench to cool this area with maximum speed.

A Brinell check is also important and the relation between the Brinell reading and the condition of the tool steel can be established by direct comparison.

On the ordinary carbon tool steel of approximately 1% carbon content, a proper anneal is indicated by a reading of 170-187.

By adding 1.50% to 1.75% of manganese to a straight carbon tool steel it is found that the austenite is rendered more stable, and that even with an oil quench, martensite is retained with resultant hardness.

When quenched in water, this steel forms martensite very quickly and deeply, with the result that the increase in volume accompanying the martensite formation sets up tremendous strains in the steel as hardened, generally causing the piece to crack.

There is also a series of oil hardening steels made, in which chromium is added to obtain the same results as with manganese. This steel requires a higher quenching temperature than when manganese is the alloy, due to the raising of the critical range by the chromium.

Steels are also classified according to the method of manufacture, as open hearth, bessemer, crucible or electric.

Each method produces steel suitable for different conditions; the bessemer being essentially a process producing cheap low carbon steel of indifferent quality, and the open hearth a good steel if properly handled, but this method is not adapted for complete refinement, as is the electric furnace or the crucible.

The crucible produces only the most expensive steels, and is a very costly process. It is not suited to produce low carbon steel, and its field is confined almost exclusively to fine tool steels.

CHAPTER XII

ANNEALING

Inasmuch as the annealing process has an important bearing upon the physical properties, mechanical treatment and subsequent effect of the heat treatment of steel after machining, it is essential that the basic principles of this operation be thoroughly understood.

Annealing is a heat treatment, preferably in a neutral atmosphere, which produces the maximum amount of ductility combined with the highest elastic limit. It is, therefore, a process by which all stresses and strains induced by machinery or rolling are released.

These changes of physical properties are due to the changes of structure caused by the heating operation, which operation consists essentially of three parts: first, heating the steel to the desired temperature; second, holding at the temperature until the steel is thoroughly heated; third, cooling.

Normalizing consists in heating the material to some point above its highest critical temperature and soaking at this heat in order to relieve crystal formation there under strain from forging, and thus obtain similar results to the same annealing which is conducted at a much lower temperature.

It is essential, of course, in all heating operations that every part of the piece be heated to the desired temperature, and so more time is required to heat pieces of larger section than those of smaller section.

The method of cooling will differ according to conditions. Very slow cooling can be obtained by allowing the piece to remain in the furnace and shutting off the heat, and thus cooling very slowly; no faster, in fact, than does

the whole heated mass of the furnace. Slow cooling can also be obtained by removing the pieces from the furnace and burying them in ashes or lime. The size of the piece again, as in heating, must be taken into account; for often a large piece placed in the air may not cool any faster than a small piece when buried. Normalizing is commonly practiced on forgings, or on material which has been subject to severe mechanical work. Annealing is used in any case where softness and fine grain size are required or where the material has not been heavily worked.

For the relief of strains only, it would be necessary simply to anneal at the lowest possible temperature; for instance, at 482° C. (900° Fahr.) to 537° C. (1000° F.), and if the work is to be maintained bright or scaleless, this anneal should be best conducted in a non-oxidizing atmosphere, in closed pots, in the presence of carbon monoxide gases, charcoal or other substances. For strain anneal we do not care particularly if the micro-structure shows lamellar or globular pearlite.

For free machining or cold work a structure of considerable softness and free shearing properties is desired. It appears that this can be best attained in high carbon steel by heating it just below the critical range, maintaining this temperature for some time, and then cooling very slowly without the presence of drafts, especially through latter part of Ar^1 range. The microstructure will show globular cementite, as in Fig. 62—that is, the hard constituent (cementite) will not then lie in layers, which are penetrated by the tool with difficulty in machining, but like shot in a box in such a way that the ferrite may be very readily cut and the cementite (in globules) pushed aside. Where steel is subject to severe distortion in cold working, this condition is essential, as it allows ferrite to flow freely into the new form without the splitting so common when laminated pearlite appears, as in Fig. 63.

Lower carbon steels may be too soft in the globular cementite condition, and to machine properly require being left in the lamellar form.

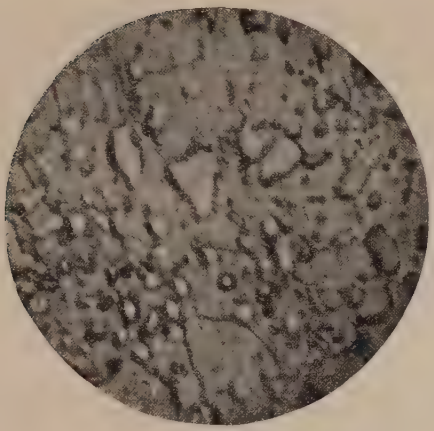


FIG. 62
Globular Cementite. Magnification, 1000 Diameters.
Carbon content, 1.05 per cent. Annealed at Ac1.
Slowly cooled in furnace

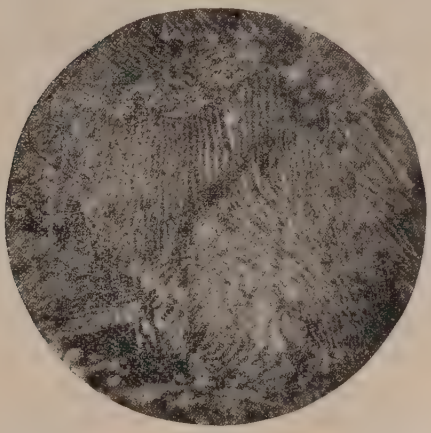


FIG. 63
Laminated Pearlite. Carbon content, 1.05 per cent.
Annealed above Ac1. Cooled slowly.
Magnification, 1000 Diameters

This is due to the predominance of soft ferrite in these steels, with such a scarcity of cementite stiffener that it becomes necessary to prevent the flow of the iron under the tool by the lines of stiffening cementite in the form of pearlite, and to obtain this proper cutting condition in very low carbon steels it sometimes becomes necessary to air or even oil quench rather than cool slowly.

When chrome steels are annealed they are frequently treated to a preliminary normalizing operation; that is, they are heated above the critical range to remove unequal working strains and to refine the grain. Then they are cooled below the critical range and finally annealed at the low critical temperature.

The following ranges of temperatures are recommended by the Committee on Heat Treatment of the American Society for Testing Materials:

Range of Carbon Content	Range of Annealing Temperature
Less than .12 per cent	875° to 925°C (1607° to 1697°F)
.12 to .29 per cent	840° to 870°C (1544° to 1598°F)
.30 to .49 per cent	815° to 840°C (1499° to 1544°F)
.50 to 1.00 per cent	790° to 815°C (1454° to 1499°F)

They also state that for steels of a manganese content greater than .75% slightly lower temperatures are advisable.

The time at which the steel should be held at an annealing heat is governed largely by the size of the piece. In order to bring the interior of large objects to an effective annealing temperature the outside may often be heated advantageously somewhat above the desired temperature. Therefore a range of temperatures is given for each range of carbon content.

The upper limit of this range applies to larger objects and also to the lower range of carbon content given.

Owing to the annealing process generally being a long one and the cooling slow, there is a great opportunity for scale (iron oxide) to form on the descending heat, owing to the contraction of the furnace gases, in cooling, drawing in air; hence, if scale is to be prevented this air must

be kept from the work by closed receptacles. The prevention of heavy scale, due to cooling from too high temperature in the presence of oxygen, is extremely important in the case of the higher carbon steels where the presence of oxide and heat will serve to oxidize the carbon in the metal nearest the scale (decarburize) often to an injurious degree.

A thick scale (iron oxide) always represents a depth deprived of carbon with a deposit of iron oxide residue. Carbon oxidizes very rapidly, and when decarbonization appears at the surface of hardened steel we find that the carbon content of the steel has been lowered for a considerable distance beyond the depth the fracture would indicate.

The control of the annealing operation by definite heats and methods unquestionably prepares steel to respond better to hardening and treating, reduces the strains and dis-

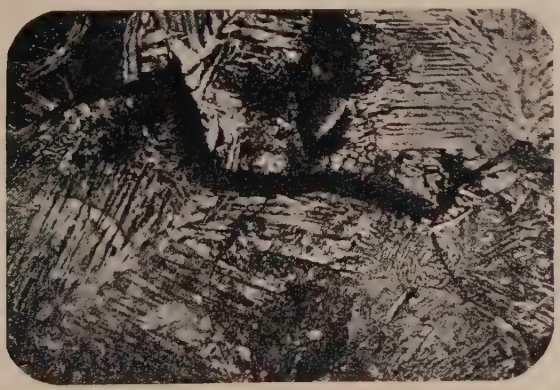


FIG. 64

Fissures Caused by Burning

tortions which are inevitable, and paves the way for a more uniform finished product.

In forging or hardening, the control of the heats has been shown to be highly important, and if the work is

heated too high the operation of forging tends to restore correct conditions. The annealing heat, however, is usually of such duration that unless cared for the heat will rise and the grain size will greatly enlarge. If the heat is carried on further past the normalizing temperature, the steel will burn, which will cause fissures, as shown in Fig. 64, weakening the steel by the loss of cohesion of the crystals.

At times the previous work of forging may have been finished at so high a point above the critical range that the structure is exceedingly coarse. Annealing at Ac_1 will not refine this grain, but if the steel is first heated to Ac_3, or above, then cooled and subsequently annealed at Ac_1 and cooled slowly, the resulting structure will thereby be refined, unless the steel has been burned.

CHAPTER XIII

THE THERMAL OR HEAT TREATMENT OF STEEL

The highest priced steel may be heat treated so improperly that the results or properties obtained are far inferior to a well-treated, cheaper grade of steel. Although these changes, due to the thermal treatment, are governed by definite laws, it must be remembered that the same treatment cannot be applied to all steels with satisfactory results but that each type responds best to its own characteristic temperatures.

The subject of heat treatment embraces the operations of annealing, case hardening or carburizing, hardening and tempering or drawing of steels. To obtain the highest physical properties from steel by heat treatment it is necessary for us to have a knowledge of the critical points and transformations occurring.

An improvement in the quality of physical properties of steel is generally brought about by heating to or through the critical range. Hardening or annealing from temperatures below these points will not be complete, nor will the structure or grain be properly refined. Quenching from temperatures higher than the critical range will result in hardening the steel, but with a coarser grain than if quenching had been done at just above the critical range.

It is universally understood that the finer the grain the stronger the steel, and to obtain this refinement the heating and cooling curves of the steel must be determined and the treatment operation confined as narrowly as possible, with respect to the critical temperatures, else the worth of the steel will be markedly impaired.

The facts about the internal modification of the steel

structure present some very interesting viewpoints to the practical man familiar with them. For instance, if a cold piece of steel (the higher the carbon the more aggravated it becomes) is thrown into a hot furnace (much above the critical range) the transformation of the pearlite and the ferrite, or cementite into austenite, is rushed far beyond the capacity of the steel to withstand it, and in passing into the austenite stage a molecular expansion occurs. Thus the phenomenon of cracking on a rising heat is explained. Similarly, if flame impinges upon the work, the transformation takes place very fast at this point, and either cracking or warping must ensue. This is why muffle furnaces and lead or salt baths give much better hardening results as a rule. Besides this, in a salt bath, upon the introduction of a piece, the salt congeals about the work, melts fairly slowly and serves to help in the slowing down of the transformation. Preheating to a medium temperature before insertion in the hardening furnace also helps the steel to pass through this critical stage without damage.

CHANGES OF STRUCTURE BROUGHT ABOUT BY HEAT TREATMENT

These changes have been summarized by Brinell about as follows:

1. When a piece of steel, hardened or unhardened, is heated to the upper critical point, Ac_3, all previous crystallization, however coarse or however distorted by cold work, is obliterated and replaced by the finest structure which the steel is capable of assuming in an unworked condition, the structure of burnt steel being the only exception. (The ferrite and pearlite or pearlite and cementite are changed to austenite.)

2. When a piece of steel, hardened or unhardened, after being heated to Ac_3, is allowed to cool slowly, it retains the fine structure which it had acquired at that temperature. It then possesses the finest structure, according to previous preparation. (The austenite reverts to the orig-

inal pearlite and ferrite or pearlite and cementite, but the grains, however coarse originally, now become the finest and best distributed possible.)

3. When a piece of steel, hardened or unhardened, after being heated to Ac_3, is suddenly cooled by quenching in cold water, for instance, it is fully hardened and retains the fine grain acquired at that temperature. The metal then possesses the finest structure which hardened steel is capable of assuming.

(The austenite, which tends to rapidly revert through several stages to pearlite, etc., is trapped before reaching the soft pearlite stage, and the resulting structure is composed of martensite, the hardest stage in steel, save the cementite, and the condition of greatest volume.)

4. When a piece of steel, hardened or unhardened, is heated to a temperature above Ac_3 and cooled slowly, the metal, whose crystallization has been obliterated by its passage through Ac_3, crystallizes again, the crystals or grains increasing in size until Ar_1 is reached, below which there is no further growth.

If steel is heated above Ac_3 and allowed to cool to Ac_3 again and there quenched, it will be fully hardened, but its structure will be coarser than if it had been quenched from Ac_3 without having been heated higher.

5. The higher the temperature above Ac_3, from which the steel is cooled or quenched, the coarser the grain.

6. The slower the cooling from above Ac_3 the coarser the grain.

7. When a piece of hardened steel is heated to a temperature below Ac_3, some of its cementite is changed spontaneously into pearlite and the metal is thereby softened. This tendency increases with the temperature, and is greatest at Ac_1. This transformation, however, is not accompanied by a change in the dimension of the grain.

Our researches and the recent work of Professors Howe and Zimmerschied have developed that:

1. When a piece of steel, hardened or unhardened, is heated to the temperature Ac_1, the cementite existing in the pearlite structure is radically altered from the previous laminated to the globular state, the resultant structure is thereby softened and rendered ductile, and the size of the grain is unchanged.

2. When a piece of steel, previously heated to Ac_3 and then either hardened or allowed to cool slowly, is thereupon heated to Ac_1 and allowed to cool slowly, especially through the lower Ar_1 range, the resultant structure shows globular cementite and is the softest and most ductile that steel may assume, the size of the grain being the smallest possible.

HEAT TREATMENT

Under the name of heat treatment are included all those processes and operations performed on metals, and particularly on steel, which affect their structure and physical properties, and which are carried out by submitting the material under treatment to variations of temperature between more or less wide limits and more or less suddenly. Heat treatment, of course, cannot begin until the first metallurgical process of obtaining the metal from the ore is completed, and in general it may be said that heat treatments are the last operations of the metallurgist, after which the metal is in the best possible condition for the service for which it is intended.

It has been remarked previously that the scientific study and practice of heat treatment is comparatively new, and the earlier successes in hardening, tempering and toughening steels were due to luck more than knowledge. The development of metallographic study and examination of the microscopic structure of metals were necessary before any real advance could be made in heat or even mechanical treatments which aimed at controlling the structure of metals, on which structure the physical properties so largely depend.

Although other metals are susceptible to modification by heat treatment, it is in the case of steel that the importance of the subject is greatest, and at the present day there are probably more people actually engaged in heat treatment operations on steel than in the production of the raw metal itself. Steel is a material which is most astonishing when it is considered what differences in qualities can be shown with so small a variation in composition and comparatively simple treatment. A tool may be seen cutting work differing but slightly from the one being shaped, as easily as an ordinary knife cutting cheese, and a steel cap on a steel armor piercing shell will serve as a veritable lubricant in assisting the projectile to pierce the armor plate, although made of steel very much alike in composition.

The processes of heat treatment are classed under a number of names, each process being a method of obtaining a certain condition of the particles of which the steel is made up. These processes are normalizing, annealing, hardening, tempering, and case hardening. There are three factors which control the results of heat treatment,—composition, temperature, and rate of heating and cooling. The composition determines the elements which may be present, the temperature influences the chemical combinations, solutions or alloys taking place between the elements present, and the rate of heating and cooling influences the degree of completeness of the combinations, alloys or solutions made possible by the temperature, as well as influencing the relative physical structure. Heat treatments thus consist in submitting a steel (or other metal) of known composition to changes of temperature between wide limits at a slower or faster rate. The apparatus required includes furnaces or means of heating, pyrometers for measuring temperatures, cooling mediums, and in case hardening, material which will provide the required carbon. It may here be observed that case hardening, or case carburizing, as it is called, should more properly be classed as a steel conversion process rather than a heat treatment operation, but it is customary to deal with it

under the latter head. In the chapter on Metallography, the critical temperatures of steel were discussed. At these temperatures changes in the steel take place, and these affect the structure and physical properties of steel, and by a hastening or slowing up of the rate of change of temperature may be checked or arrested in their progress, possibly even prevented from taking place at all, the degree of completeness of the changes determining the final physical characteristics of the metal when it has returned to atmospheric temperature. We have briefly described how these changes have to do with the way the iron and carbon are associated, both with each other and with the impurities, phosphorus, sulphur and silicon, and the alloying metals such as manganese, nickel, chromium, vanadium, etc., and also how the structure with regard to the size of crystalline grains is influenced, and it is the business of the heat treater to know the nature of these changes and arrange his treatments so as to take advantage of them.

The actual carrying out of some apparently simple processes in heat treating is accompanied by many practical difficulties which may result in ruining the piece under treatment. It is difficult to avoid the cracking of pieces which are so shaped that unequal contraction and expansion are liable to occur; it is not always easy to determine temperatures very accurately, and the manipulation of hot material is inconvenient.

One of the first considerations in heat treating is the method of obtaining and applying heat to the material to be treated. There are many types of furnaces; depending, of course, on the character of the work to be accomplished. Fuels used may be coal, coal gas, natural gas, producer gas, oil and electricity. The choice will depend very largely on the cost in the particular locality. Gas or oil fuels are more easy controlled than coal.

Heating must be arranged so that the piece is uniformly heated, and even with the use of pyrometers it is difficult to insure uniformity when a number of articles

of different shapes are being heated together. The character of the gases present in the furnace also must be considered. If they are of an oxidizing nature there will be a large production of scale, and the best results are obtained when the atmosphere in the furnace contains no oxygen, very little reducing agents, and is under a slight pressure. The material in the furnace is heated by the hot products of combustion of the fuel, and also by radiation from the walls of the furnace. Since the pieces placed in a furnace receive heat on their surfaces it will take longer to heat up a piece of large cross section than a small one, and the pieces should be so arranged or supported in the furnace that the heat will be applied evenly over the whole surface of the piece at the same time. The arrangement, therefore, of the charge in the furnace is of great importance, and it is in this arrangement and proper regulation of the speed of heating where experience and intelligence are required, and even with the best of furnaces, fuels and pyrometers, there still remains a human factor on which much of the success of the operation depends. It is impossible here to discuss the design of furnaces, and only the general principles of the main operations can be indicated.

In the heat treatment of steel it is essential that there be uniformity in the material in order to obtain uniform results, the composition must be homogeneous, and there must be freedom from segregations and defects. There are certain difficulties in some heat treatments which appear insurmountable. It is not possible to cool every part of a mass of steel of considerable size with the same degree of rapidity; the internal parts cannot be cooled as quickly as the outside parts; therefore, small pieces are more susceptible to successful heat treating than large ones.

Hardening is in a certain particular the reverse of annealing because this operation hardens instead of softens the steel. It consists in heating followed by more or less quick cooling, usually known as quenching. The quench-

ing or sudden cooling has the effect of holding the iron carbide in solution by not giving it time to again separate and form pearlite. There is no difference, of course, in the effect of the heating in annealing or hardening, the difference only occurs in the rate of cooling. In annealing the changes which take place at the critical points are allowed to proceed to completion in both heating and cooling; in hardening the changes can take place in the heating, but are not allowed to take place, or are checked, in the cooling.

The ferrite and cementite of carbon steels at ordinary temperatures change to a solid solution called austenite at the critical or transformation temperature. On cooling, austenite changes back, but passes through transition forms, known as martensite, troostite and sorbite, all being different associations of ferrite and cementite. The hardest condition is obtained when the change is arrested so that martensite is the chief constituent. This is obtained by cooling, or quenching, in water from a temperature above the highest transformation point. Troostite is less hard than martensite, and is obtained by quenching less rapidly, as done with small pieces by quenching them in oil, or may be obtained in the center of larger pieces which have been quenched in water, and whose outside parts are chiefly martensite. Sorbite is obtained by a slower quenching which may be in oil or in molten lead. It must, of course, be understood that the critical temperatures, and also the constituents, depend upon the carbon content of the steel being treated.

After hardening, a process for tempering and toughening may be necessary. The quenching first produces a hard and brittle condition which may require to be reduced or mitigated. This is also called Drawing or Draw Tempering, Letting Down, etc. The first quenching from the original heating may produce a large amount of martensite. Now if the piece is again heated, but only to a temperature less high than the first heating, the change in the constituents will be again allowed

to proceed and the martensite continue its transition into troostite and sorbite. By proper regulation of time and temperature the proper amount of martensite, together with the right quantity of troostite, may be preserved, giving the desired degree of hardness and toughness. This drawing process also relieves strains which have been set up by the hardening quench.

In hardening operations it is often more convenient to heat the piece in a bath of some molten material rather than in a furnace. The temperature can be exactly regulated and the piece be very uniformly heated. Molten lead and various salts can be used as heating baths. Lead has certain drawbacks. When heated to more than 1200° F. it begins to give off poisonous fumes, and also is so heavy that steel will float on it and must be held under the surface. There are many salts which do not have these objections.

Baths for quenching may be of various liquids. Water, brine and various oils are used. Water and brine are the fastest quenching means, oils being slower. The initial temperature of the quenching bath also has influence on its action in cooling, and further, the volume of the quenching liquid must be in proportion to the amount of heat to be absorbed in order that a definite rate of cooling be obtained. Water has so rapid an action that the internal strains set up by the quick contraction due to cooling are liable to cause cracks, the fissures occurring towards the end of the cooling operation.

In industrial practice proper means are necessary for maintaining the cooling liquid at the correct temperature because it absorbs the heat from the piece being quenched, and in the case of oil the constant use may also heat it up to ignition point. They may consist of circulation to carry off the heat by convection and radiation, or by some artificial refrigeration.

Whether the structure of a piece is martensitic, troostitic, sorbitic or pearlitic determines the physical characteristics of the metal.

If it must be as hard as possible, such as a part made to resist wear with little stress, then the endeavor is to retain the martensite by the quickest possible cooling.

If tougher and yet be quite hard, as a chisel, it is quenched to retain the martensite and then converted into troostite by reheating to 450° F. to 500° F.

If the work is to resist bending and yet be tough, it is reheated after quenching to convert the martensite into sorbite, which gives the metal its greatest toughness.

Just as alloys retard the transformation of the austenite to martensite, so they resist the changes from martensite to troostite, etc., and with alloy steels it becomes necessary to increase the drawing temperature considerably.

In quenching water hardening carbon steels it is often difficult to prevent cracking due to strains set up in the martensite volume change. By quenching, so as to avoid flanges, etc., from being too quickly cooled, it is possible to avoid a considerable amount of cracking.

It is in this particular phase that experience and intelligence count the most.

Warpage, strains and soft work can be reduced to the minimum in the hands of a skillful, experienced and alert tool hardener, and the maximum obtained from a poor hardener of little knowledge.

Heat treatment, as applied to tools, requires considerable skill, but as applied to mass production of medium carbon or alloy steel parts, it can be reduced to routine work if the supervision is sufficient where common labor is employed.

The heat treatment of steel is a broad field and covers a wide range of application with many tests to satisfy.

Such factors as quality of steel, design of section, etc., are beyond the control of the heat treater, and yet the results obtained at most plants today are surprising in the small percentage of rejected material after heat treatment.

CHAPTER XIV

FURNACES FOR HEAT TREATING

In building a furnace for a heat-treating operation, the size and number of pieces of work to be handled, the fuel available, and the permanence of the installation should be carefully considered.

If the work is small in size but in very large quantities, a continuous furnace should be given careful consideration, since with furnaces of this type operating labor is reduced to a minimum and uniformity of the product better controlled. Even for large sizes such as front axle forgings, if there is a continuous output required, the operation of a successful continuous furnace will soon pay for itself in reduced labor costs.

In designing continuous furnaces it is generally necessary to use a heat resisting alloy, which increases the cost considerably.

For small parts the rotating hearth, or table type, is preferable, and on large work the traveling hearth of the chain grate type is more suited to the work.

For most work, however, especially where it is not considered advisable to invest much money in the heat treating, the ordinary underfired, so-called semi-muffle furnace is probably the best.

The walls should be thick to retain the heat, and insulating brick should be used where possible. If the installation is to be permanent the furnace should have a good foundation, and burners and piping of best design should be installed.

If it is deemed advisable to build furnaces for a heat-treating department, great care should be exercised that they are ample in size, and that there is a proper relation between combustion space, flues, and working spaces.

For most work, using good burner, with good fuel oil, a pressure of 30-40 lbs. per square inch on the oil and a pressure of 8 to 12 oz. per square inch on the air is sufficient. With gas as a fuel the gas pressure is generally about the same as the air.

When oil is used as a fuel, an effort should be made to obtain what is known as distillate, having a specific gravity of from 30° to 40° Baumé, and reasonably free from water and foreign matter. Heavier oils are more difficult to handle, but cheaper, due to higher B. T. U. value per gallon.

In order to check the quality of the fuel oil obtained and to be sure that even if the specific gravity is correct, the oil is not a mixture of the heavy still residue with lighter distillate, it is customary to check the free carbon by means of a distillation test known as the Conradson test.

If the fuel oil is a mixture, the heavy residue will settle out and cause a great deal of trouble by clogging burners.

Fuel oil should be heated to 180°-200° F. when it reaches the burners in order to obtain maximum economy and complete atomization without the use of a great amount of excess air.

All pipes should be accessible, with sufficient valves, unions, etc., to permit of easy cleaning and allowing them to be shut off in case of fire.

Furnaces for carburizing must be suited to the character of the work.

If a rapid carburizer is used requiring small carburizing boxes, the furnaces are preferably small, depending on the number of boxes available at a given time for the same furnace.

With a rapid carburizer and small boxes, it is essential that each box be equally heated, and this condition is best met in a small furnace, with flues arranged to give the most uniform heating.

It should also be decided whether the hearth level is to be at the floor or the usual distance above the floor.

If the boxes are large and the heats long, it is easier to handle the work on a truck which runs on the floor, and having a long handle it is possible for one man to carry the heaviest boxes in and out of the furnace.

For elevated furnaces a fork suspended from a traveling hoist is used.

The floor level furnace must be built to stand the heavy trucking on the hearth, and if underfired it is necessary that a very good grade of fire brick be used for piers and floor. With wide truck wheels, heavy loads, and the very best fire brick, an underfired furnace should operate continuously for one year, without shut down, when fuel oil is used; when burning gas a longer life should be obtained.

The floor of a furnace should be raised slightly above the grade line to allow for the wearing away of the floor.

By using underfired furnaces, with burners in front and flues in the door or at each side of the door, the gases must travel to the front of the furnace, which is naturally cooler, and thus keep this part of the furnace hot.

An underfired furnace is much superior to a direct fired furnace for obtaining uniformity of temperature, and the cost of operation is little, if any more, since the underfired furnace is generally the more efficient.

All carburizing furnaces should be equipped with pyrometers to indicate as nearly as possible the true temperature of the work. This is done by bringing the thermocouple as nearly as possible in contact with the work.

In starting a new furnace it should be brought slowly to heat in order to permit the brick work to expand uniformly, and the first work put in should be scrap material in order to check the uniformity of its heating properties.

Furnaces for annealing large pieces are generally of the movable or car-bottom type.

Smaller work is annealed in furnaces similar to the standard carburizing furnace.

When a furnace is to be shut down the air, as well as the fuel, should be shut off, especially when work is cooling after annealing.

Carburizing furnace doors should be well fitted, using steel castings in preference to cast iron, and using a Silo-cel lining of from 3″ to 6″, which lining must be carefully anchored to the door.

Furnace burners should be given proper attention, and necessary steps taken to insure good oil or gas at a constant pressure.

Regulators are now made which will hold the operating temperature of an oil-fired furnace to within plus or minus 5° F. without attention.

FIG. 65
Hardening Furnaces at New Departure Mfg. Co., Bristol, Conn.

FIG. 66

Heat Treating Furnaces at New Departure Mfg. Co., Bristol, Conn

CHAPTER XV

HARDENING WITHOUT SCALING

In heating for certain hardening and drawing operations it is often necessary to avoid all scaling or oxidation. The only way in which this can be accomplished is to heat the articles out of contact with the air. One of the cheapest and most convenient ways to accomplish this object is the use of a proper salt bath.

It is perfectly obvious that the salt bath used must melt at a temperature lower than that which is to be used in the treatment operation. It is not always possible to find a single salt which will accomplish this purpose. A mixture of two salts will have a fusion point somewhere between the melting point of the individual salts. In some cases the mixture will have a fusion point lower than either of the salts when melted individually.

Barium chloride has a melting point of 955° C. (1751° F.); calcium chloride has a melting point of 774° C. (1420° F.). As both of these salts are comparatively inexpensive, mixtures of the two can be made which will have a melting point between the ranges indicated above.

Many salt baths give off fumes which are very corrosive, and in some cases this can be overcome by the use of other salts in small proportions, such as carbonates.

The following table gives the melting point of a number of the more common salts, and by the help of the table practical heat treaters can select a pure salt or make up a mixture which will give the melting point desired. Before attempting any experiments it is well to determine the price in any given community at which a number of the salts can be secured.

MELTING POINTS OF CERTAIN SALTS

Material	Symbol	Melting Point °C.	°F.
Barium Carbonate	$BaCO_3$	1360	2480
After loss of	CO_2	900	1652
Barium Chloride	$BaCl_2$	955	1751
Barium Nitrate	$Ba(NO_3)_2$	575	1067
Boric Acid	H_3BO_3	184	363
Borax	$Na_2B_4O_7$	561	1041
Calcium Chloride	$CaCl_2$	774	1420
" Nitrate	$Ca(NO_3)_2$	499	931
" Sulphate	$CaSO_4$	1360	2480
Magnesium Chloride	$MgCl_2$	708	1309
Mercuric Chloride	$HgCl_2$	265	509
Potassium Carbonate	K_2CO_3	909	1669
" Chloride	KCl	772	1421
" Nitrate	KNO_3	337	638
" Cyanide	KCN	556	1035
Sodium Borate	$NaBO_2$	966	1767
" Carbonate	Na_2CO_3	849	1561
" Chloride	$NaCl$	800	1472
" Cyanide	$NaCN$	560	1040
" Nitrate	$NaNO_3$	316	601
" Metaphosphate	$Na_4P_4O_{12}$	617	1138
" Sulphate	Na_2SO_4	888	1632
Zinc Chloride	$ZnCl_2$	262	504

The salt baths have the disadvantage in that they require frequent renewal and are expensive to operate. The fact that the temperature of the work heated in a salt bath can be closely regulated, and that overheating is impossible if the bath itself is at the proper temperature, is a great point in its favor.

Nitrate baths are often used for drawing alloy steels, which must be drawn between 600° F. and 1200° F. For this purpose they are well adapted.

Lead baths are used for hardening steel without scale and give very good results.

The lead must be kept clean and free from the oxide of lead which forms on the surface of the bath unless it is covered with a reducing substance, such as charcoal or petroleum coke.

Since lead has a much greater specific gravity than steel, it is necessary that means be provided for keeping the

steel to be heated submerged. The steel absorbs heat from the lead much quicker than it does from a salt bath or from furnace gases, and, therefore, the lead bath heats more rapidly than either the open furnace or the salt bath.

They are much used for this reason, but their more extensive use is restricted because of the difficulty of preventing oxidation of the lead and the troubles involved in handling the work through the furnace.

Hardening without scaling can be done in fuel fired, muffle or in electrically heated furnaces, if care is used to prevent any circulation of air, and charcoal is heated with the work.

Articles may be packed in mica or charcoal, to stop scaling, or may be dipped in a thin solution of clay.

It is practically impossible to heat work in the open or semi-muffle furnaces without some scaling, because of the presence of some oxygen in the products of combustion.

Coating the work with substances like borax, salt, etc., are satisfactory for laboratory purposes, but do not work out in regular production, because of the uncertainty of results.

Cyanides are also used as a heating medium for hardening steel free of scale, but owing to the carburizing action of the cyanide upon the steel, its use as a heating medium is limited.

When salt or lead baths are used they should be hooded with a vent pipe to the roof to carry away any poisonous fumes which may be given off.

CHAPTER XVI

QUENCHING

In order to utilize the properties imparted to steel by the addition of carbon, it is necessary to heat the steel through the critical range, and then obtain the hardness desired for the purpose in hand by regulating the cooling speed.

The rate of cooling of a high carbon steel from above its critical range determines the amount of martensite, troostite, sorbite or pearlite present.

Generally it requires a very rapid rate of cooling to retain the martensite, which is the hardest condition, and hence in order to harden high carbon steel means must be provided to cool the piece as quickly as possible.

This is most easily accomplished by the use of cold water, either by submerging the work or by powerful sprays, or both. A cold water quench is very severe and causes enormous strains in the hardened work, due to the volume change which occurs in the formation of martensite. A water quench is, therefore, likely to cause fracture if too severe, especially if the work is so shaped that one portion has set before the other passes through the martensite zone. This is the case of heavy sections with thin ribs, or, in fact, any piece when there is an abrupt change in section.

High carbon pieces, which will crack when quenched in cold water, are quenched in oil, which, being a much slower cooling medium, forms much less martensite and more troostite than the water quench. Since the troostite formation is not accompanied by a volume increase as is the martensite, the strains set up are much less severe and the piece is, however, not so hard.

It is important, when quenching in water, to see that

conditions are such that a uniformly hard result is obtained, and that no soft spots occur.

Soft areas on high carbon tools are generally caused by the quench not being designed properly, there being spots on the piece where the water pressure is not sufficient to break down the cushion of steam surrounding the hot piece.

When a hot piece of steel is plunged into a bath of water, the heat immediately converts the water surrounding the work into steam, and unless this steam is carried away, either by gravity or the pressure of the water, the rate of cooling becomes the same as if the work had been quenched in steam. It is, therefore, necessary to see that the whole of the surface of the article being quenched is in direct contact with its quenching medium. This is done generally by means of high pressure sprays arranged in a fixture to suit the work.

In the consideration of oils for hardening purposes, care should be exercised to select an oil which will give uniform quenching speed, which will not produce gaseous vapors at low temperatures, and which will not oxidize or thicken with repeated use.

The quenching speed of an oil depends on its refrigerating properties, and also on its fluidity or viscosity. Should an oil decompose by continued use through absorbing oxygen from the air, its refrigerating properties will change, and the thickening up which decomposition entails, will reduce the quenching speed correspondingly.

The more viscous an oil the slower will be its quenching speed. Therefore, it is desirable to use an oil which is fluid when fresh, and which will not thicken and decompose with use. Such variation might be accompanied by corresponding variations in the hardness of the steel of from 50 to even 100 per cent.

Practical tests have proved that mineral oils of low fire test break up and pass through a series of distillations, owing to the action of the heat of the metals, and in this

process of breaking up they alter, leaving a residue similar to that obtained when they have been distilled more rapidly in a regular manufacturer's still.

QUENCHING SPEED VARIES WITH VISCOSITY

For years animal and vegetable oils of a semi-drying nature, such as whale, fish, cottonseed and linseed oils, were used almost exclusively for the hardening of steel. These oils would harden satisfactorily when fresh or first used, but on continued use the quenching speed would lessen. Investigation has proved that the quenching speed varied with the viscosity of the oil, which would increase in proportion to the amount of oxygen absorbed. The fact that uniform quenching speeds could not be obtained with the oils in general use for this purpose instigated considerable research along these lines.

The more viscous an oil the slower its quenching speed. It was found that the animal, vegetable and fish oils could not be depended upon to give uniform results. They all would oxidize, become thick with continued use, and oft-times precipitate a sludge to the bottom of the quenching tank. Mixtures of such oils with mineral oils, in varying proportions, were tested without any marked degree of success.

The whole family of animal, vegetable and fish oils have been tested repeatedly in a practical way. Exhaustive tests have been made with what is known as an animal hydrocarbon oil (see journal of the American Chemical Society, September, 1910), which is a distillation of wool grease. This grease was subjected to a very severe distillation, and the resultant product was an oil possessing a smaller percentage of residue and solid matter in suspension than any other oil known; in fact, this distilling process produced an unoxidizable animal hydrocarbon oil.

Wool grease in itself is a pure animal product possessing about 50 per cent. unsaponifiable matter. The extreme fluidity and penetrating properties of this distilled oil con-

vinced our research department that it possessed marvelous powers of heat circulation. It was also discovered that this oil which possessed marked refrigerating properties (heat-absorbing properties would be a better term), did not decompose after repeated use, nor show the slightest further fractional distillation even under intense heat.

When quenching steel it is also very important that there be plenty of water or oil supplied to the hot work so that the temperature of the bath does not rise higher than about 120° F. This necessitates the use of quenching tanks of the proper size.

The size of quenching tanks required for any particular class of work will first be governed by the size of pieces to be treated. As all hardening baths should be so designed that the temperature of the bath can be kept within reasonable limits, even when a large amount of work is being treated, the following information is given as an assistance in the design of such equipment.

When water is used as a quenching medium, circulation is necessary, and this is usually provided for by a large intake pipe at the bottom of the tank, connected with a suitable water main. As the cost of water is generally very low, it is very seldom that the attempt is made to refrigerate the overflow water.

The refrigeration, or cooling, of the oil in the quenching tank may be accomplished in several ways. An ammonia refrigerating machine, where either the oil is circulated, or cold brine is circulated in pipes through the oil, can be used. When a large supply of cold water is available, the refrigeration can be accomplished by circulating cold water through the oil tank by means of suitable coils, or the oil can be circulated through a cold water tank. In general, the latter practice is to be preferred as there is less tendency for the coils to leak, owing to the low pressure at which oil is generally pumped through the cooling pipes, and further if leakage does occur, it is immediately seen by the oil rising to the

surface of the cooling water. When an oil tank is cooled by a coil of water pipes, the water is very often circulated under relatively high pressures, and if any leak occurs, the oil bath will become contaminated with water which is difficult to recognize, until after a high percentage of unevenly hardened and broken work has been produced. The system should be so arranged that the hot oil is removed from the top of the quenching tank, and after cooling returned to the bottom of the quenching tank.

The specific heat of steel at 1550° F. is 0.166 B. T. U. That is, if you raise one pound of steel 1° F., it will require 0.166 B. T. U., and when one pound of steel is lowered 1° F. it gives off 0.166 B. T. U.

Quenching steel from 1550 to 150° F. equals 1400° F. taken from the steel.

Therefore, one pound of steel from 1550 to 150° F. equals 1400 x 0.166 B. T. U., or 232 B. T. U. taken from the steel.

Then the number of pounds of steel to be quenched per hour, multiplied by 232 B. T. U. equals the number of B. T. U. which must be extracted from the oil per hour by the cooling system.

Quenching one pound of steel in 10 pounds of oil raises the temperature 47° F.; therefore, if you should quench 1,000 pounds of steel per hour in 10,000 pounds of oil weighing 7¼ pounds to the gallon, or 1,240 gallons, the temperature of the tank will rise 47° per hour without a cooling system.

The length of pipe required to cool the oil is dependent upon the temperature of the cooling water, the speed of circulation of the oil, and also the quantity and circulation of the water through the cooling system. Several excellent devices are on the market for this purpose, and Figs. Nos. 67 and 68 illustrate a device which has proven to be very efficient.

FIG. 67

FIG 68

A STUDY OF QUENCHING MEDIA

In studying the relative rate of cooling of several media it is advisable to select certain temperature ranges for convenience in comparison.

The rate of cooling between the range 1472° F. and 1122° F. is considered in this discussion as the rate of

cooling through the critical range. This may be open to very serious objections, the principal one being that the reactions which take place in passing through the critical point in cooling are not completed in this temperature zone. The hardness brought about by quenching is commonly explained as being due to the retention of transition constituents. Granting that hardness is brought about in this manner, in order that the material quenched should retain its hardness at atmospheric temperature, it is necessary that the transition constituents formed in quenching be retained. The explanation of the retention of hardening constituents on quenching is often based on the statement that the critical point is lowered by rapid cooling. There is certainly some very good evidence which indicates that the final hardness of the quenched piece is regulated not only by the rate of cooling through the critical range, but also by the rate after the material has passed through the critical range. In other words, a quenching bath composed of some imaginary medium might cool the steel exceedingly rapidly through the critical range, but after this point is passed the rate of cooling might be very slow. Such being the case, although the transition constituents might be retained in passing through the critical range, they would be tempered and reduced to lower transition constituents by the slow cooling subsequent to passing through the range.

For convenience in comparison, the range 1122° to 752° F. has been considered in this respect as the tempering zone. Another fact that seems quite well established is that the cracking of a piece of steel during the quenching operation takes place in the lower temperature ranges. Distortion might be brought about by a too rapid cooling through the critical range, but a piece of uniform section could only be cracked or checked by rapid cooling in a zone where the steel is no longer plastic. For this reason the temperature range 752°-392° F. is considered here as the dangerous or cracking zone. Although rapid cooling below 392° F. is exceedingly dangerous, it is very im-

probable in practice that a forging would be left in the quenching medium below this temperature.

Having, therefore, established three zones, the limits of which will vary with the composition of the steel employed, it is only necessary to compare the rate of cooling in these three zones in order to arrive at the relation between any group of quenching media.

APPARATUS

The standard test specimens employed in obtaining the data given here were of the design shown in Fig. 69. The analysis of the steel employed was as follows:

	Per cent.
Carbon	0.45
Manganese	.84
Silicon	.15
Sulphur	.05
Phosphorus	.02

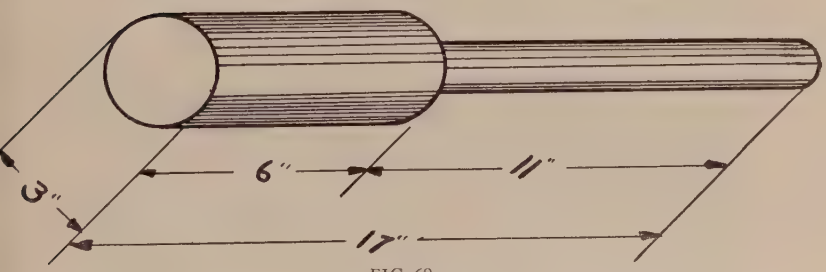


FIG. 69
TEST BAR

Pyrometer.—Inserted in the test bar was a calibrated base-metal thermocouple which was used for temperature measurements. A similar couple was placed in the heating furnace so that the time of soaking could be carefully controlled. An indicating potentiometer was employed for reading the millivoltage of the couples.

Quenching Tank.—The quenching tank consisted of a galvanized can provided with an asbestos cover and stir-

ring device. To prevent heat losses, the tank was insulated with asbestos pulp six inches thick. It was not desired to provide for any cooling facilities in this investigation. In other words, to obtain comparable results, two courses were available; the first was to use a circulating system of such construction that the bath temperature would not change throughout the course of the experiment. The other alternative was to entirely avoid any cooling of the medium during the course of the experiment. Any standard condition between these two extremes would have been very difficult to obtain.

Procedure.—The test bar was heated in an electric furnace, observations being taken of both the furnace and test bar. The test bar was heated to 815° C., and held for one-half hour. The furnace was maintained constant during this soaking period, the maximum difference between the test bar couple, and furnace couple, not being allowed to vary more than 5° C.

After the soaking period of one-half hour, the test bar was removed from the furnace and immediately immersed in the quenching medium. The depth of immersion and location in the tank were maintained constant throughout the several experiments. The stirring apparatus was immediately started after the piece was immersed. Two thermometers, one at the top and one at the bottom of the liquid, were used in taking temperature observations of the quenching medium. Temperature observations were taken by means of the couple and indicator mentioned above, and a chronograph was employed for recording the time required to cool each 50° C. interval.

The surface area of the test bar was 69½ square inches and its weight 11.25 pounds.

A typical data table obtained, from which the conclusions in this discussion were made, is shown on page 175.

HOUGHTON'S No. 2 SOLUBLE QUENCHING OIL

EXPERIMENT No. 1

(Initial bath temperature, 28° C: final bath temperature, 57° C: rise in temperature, 29° C.)

Temperature in ° C		Time required for cooling in seconds	Time required from 800° to 600° C seconds	Time required from 600° to 400° C seconds
From	To			
800	700	40	64	.....
700	600	24		.....
600	500	24	..	65.50
500	400	41.50	..	
400	300	59	..	.....
300	200	98	....	.....
200	120	171	..	.....

All of the data obtained are summarized in the tables shown on page 176:—

CONCLUSIONS

Some of the data obtained in this investigation have been summarized in a diagram which is inserted at the end of this volume.

The abscissae represent the initial temperature of the quenching bath, whereas the total time to pass through any given range is represented by the ordinates of the curves. An examination of the various curves enables the statement of several well-defined conclusions.

Water, with an initial bath temperature of 40° C., is a very effective medium in cooling through the quenching zone. The rate of cooling of the same medium in the tempering zone is much more rapid than in the hardening zone. The rate of cooling in the ranges 400°-300° and 300°-200° is also very rapid, and it is believed that study of this curve, with particular reference to the rate of cooling in the last two-mentioned zones, will explain the great liability of cracking when water is used as a quenching medium, if the piece is allowed to remain in the quenching bath until cold. Very little tempering can take place below 400° C., and the sooner the piece is removed from the

SUMMARY OF RANGES CHECKED

	Initial temperature (° C)	Time required to drop from				Final temperature (° C)	Rise in temperature (° C)
		800° to 600° Seconds	600° to 400° Seconds	400° to 300° Seconds	300° to 200° C Seconds		
Houghton's #2 Soluble Quenching Oil	28.0	64.50	66.25	59.25	97.50	56.0	28.0
	58.0	63.50	67.00	62.25	112.50	83.0	25.0
	86.00	50.00	50.75	59.00	111.00	110.00	24.0
Water	26.0	28.75	15.25	11.50	20.00	40.0	14.0
	41.0	28.75	14.75	11.50	19.25	55.0	14.0
	92.0	170.00	26.75	14.25	26.25	99.0	7.0
	80.0	82.00	18.00	10.75	17.75	91.5	11.5
Whale Oil	26.0	68.25	39.50	36.00	77.00	51.5	25.5
	29.5	64.75	37.50	37.50	93.25	54.5	25.0
Mean	....	66.50	38.50	36.75	85.13	....	....
Max. Difference	....	3.50	2.00	1.50	16.25	....	....
Whale Oil	55.5	50.50	29.00	28.25	67.75	79.0	23.5
	56.0	54.00	35.00	35.25	91.25	79.5	23.5
Mean	....	52.25	32.00	31.75	79.50	....	....
Max. Difference	....	3.50	6.00	7.00	23.50	....	....
Whale Oil	90.0	66.25	42.25	48.50	137.50	110.5	20.5
	91.5	65.50	55.00	68.75	148.50	111.5	20.0
Mean	....	65.87	48.62	58.62	143.00	....	....
Max. Difference	....	.75	12.75	20.25	11.00	....	....

bath after having reached this temperature, the less will be the danger from cracking.

It is of particular interest to note that when the initial temperature of the water bath was 80° C., the rate of

cooling through the hardening zone was much slower than that which existed for the oils. This, however, does not apply in the tempering and dangerous zones. In other words, hot water as a quenching medium gives a very queer condition of slow cooling through the critical range, followed by rapid cooling in passing through this range. This is a most undesirable condition and it is believed that the use of hot water as a quenching medium should in all cases be avoided. It is not believed that too much emphasis can be placed upon this point, and it is believed that some manufacturers are finding themselves in trouble due to this cause. To recapitulate this statement, hot water as a quenching medium will produce very slow cooling through the critical range, followed by rapid cooling through the tempering and dangerous zones. The result is that proper hardening never takes place, while at the same time the dangers arising from cracking are in no way lessened by the use of hot water.

Turning next to Houghton's No. 2 Soluble Quenching Oil, it is to be noted that the rate of cooling through the quenching zone increases as the initial temperature of the bath increases.

The rate of cooling in whale oil first increases through the quenching zone as the temperature of the bath increases, but as the temperature of the bath is further increased the rate of cooling through this zone decreases.

Assuming then, that an ideal quenching medium is one which gives a very rapid rate of cooling in the quenching and tempering zones, while at the same time giving a slow rate of cooling in the danger zone, it is evident from these curves that water does not meet the ideal conditions.

Water falls short of meeting the ideal conditions in giving a rapid rate of cooling in the danger zones where cracking will occur. This could be overcome by withdrawing the quenched pieces from the quenching bath at the proper temperature, but this is never convenient, and

is not a practical measure when small work is being treated.

Whale Oil gives a more rapid rate of cooling when the initial bath is at certain temperatures, as is shown by the curves, but it is open to the very serious objection that the rate of cooling is materially affected by the bath temperature. This tends to produce erratic results in quenching.

In developing Houghton's No. 2 Soluble Quenching Oil, the attempt was made to produce an oil which would obtain the maximum rate of cooling through the quenching and tempering zones, with the minimum rate of cooling in the danger zones. At the same time, the attempt was made to produce an oil whose rate of cooling would not be affected by the bath temperatures usually encountered in a commercial installation. It is believed that an inspection of the curves will show that this has been successfully accomplished.

CHAPTER XVII

CARBURIZING

Cementation or carburizing is one of the oldest metallurgical processes used in the production and heat treatment of steel products. It was used to produce the first steel manufactured commercially, known as shear steel. The cementation process has, however, undergone the least improvement and refinement of any of these processes.

The cementation process consists in subjecting grades of the best wrought iron to a treatment where the bars are packed with charcoal in suitable containers, called coffins, and raised to a heat of 900°-950° C. for six or seven days. The total time, including heating up and cooling down, is from ten to fourteen days, according to the quality desired. By this means the initial carbon content is raised from 0.05% to a maximum of 2.0%. The bars when removed from the furnace are covered with blisters for which reason the steel is sometimes called blister steel. This condition is due to the action of carbon on the oxide of iron in the slag (ferrous silicate), contained in all wrought iron, producing carbon monoxide gas, the expansion of which causes the blister. From these bars, by forging and remelting, we obtain the finest quality of crucible made steel.

(This process is still very extensively used for crucible melting.)

Case hardening finds numerous applications in engineering, such as in armor plates where a very hard exterior is required with a tough interior, and is an application of the cementation process.

The present day production, especially on the automotive side, has created a wide demand for steel with the

hard wearing surface or case and a soft, shock-resisting, tough core. In spite of this demand and the importance of the process, it has been neglected, while other metallurgical, and especially heat-treatment processes, have been refined to a considerable extent. In applying the carburizing process, some of the fundamental principles of metallurgy have been neglected.

It is true, there are a great many factors that enter into this process which are more or less variable. Its successful application means standardizing methods and materials, and eliminating variables, as well as making use of good metallurgical knowledge and judgment.

The mechanism of the process is explained by the fact that iron or mild steel absorb, by a sort of diffusion process, carbon from adjacent carbonaceous material. It also absorbs, by a process which still is under discussion, carbon from carbon monoxide, cyanogen, and hydrocarbon gases.

There are three forms of carbonaceous material used in practice—liquids, solids and gases. The second class is used most extensively, and is the class chiefly under discussion in this book. However, in the use of solid materials, the gaseous products formed by the heating of such materials plays an important part in the commercial carburizing process.

The various elements entering into the successful production of carburized products are:

(1) The iron or steel used, its composition, physical condition, etc.

(2) The carbonaceous material, its composition, character, physical properties, uniformity, etc.

(3) The method of heat application, its degree, character, uniformity, etc.

(4) The time of exposure to the carburizing temperature.

(5) The container or carburizing box, its form, composition, method of sealing, etc.

(6) The subsequent heat treatment of the products.

There are some other minor factors that enter in, such as size, shape and surface condition of the product, method of packing in containers, rate and method of cooling after completion of the process, etc.

If all of these variables are standardized or put under careful control, much of the present complaint concerning the uncertainty of the carburizing process will be eliminated.

For many purposes the carburizing process produces the ideal metallurgical state in the product. By proper processing and heat treatment there can be produced a part with these characteristics: a strong and very tough core; an exterior shell in which the carbon content increases gradually from that of the core to that of a hard steel, and so treated that at every depth in this shell, or case, the steel is properly refined. The graduation of carbon in the case may be gradual or abrupt; the maximum carbon content may be high or low. The resulting physical properties may be varied, as desired within wide limits.

The steel used for carburizing should be made in accordance with good practice. It should be free from physical defects, such as pipes, laminations, segregations, etc., since carburizing and subsequent heat treatment tend to develop and enlarge upon all inherent defects.

The Metallurgical Department of the Timken Roller Bearing Company, one of the most extensive users of carburizing material in the United States, has made an important contribution to the knowledge of carburizing and of the importance of using steel of the proper physical quality for carburized parts of importance.

They have determined that the carburizing results are directly connected with the condition of the steel as it leaves the melting furnace, and that dissolved impurities, especially oxides, have a very great influence on the results obtained in case hardening.

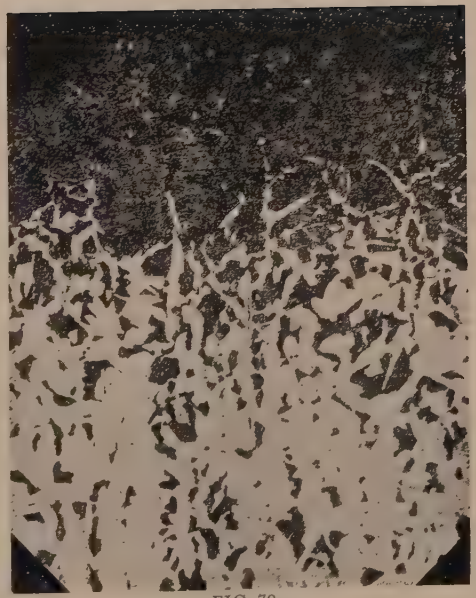


FIG. 70

Eutectoid Case, 50 Diameter
Normal Steel

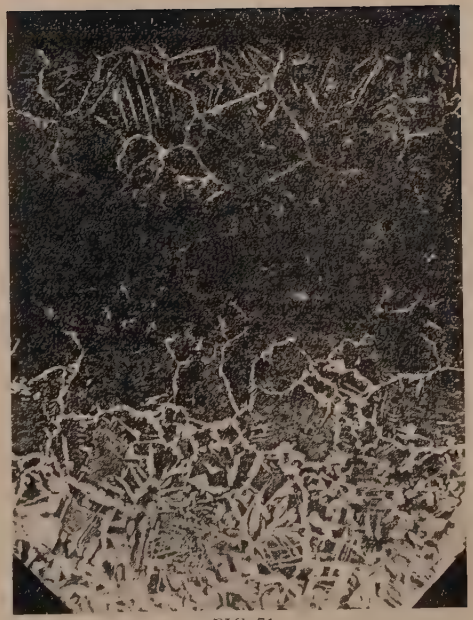


FIG. 71

Hypereutectoid Case, 50 Diameter
Normal Steel

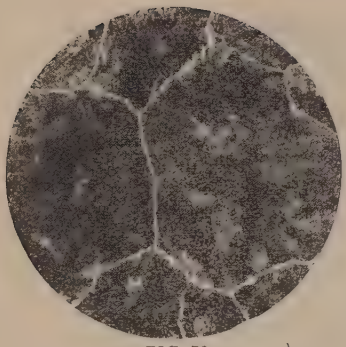


FIG. 72
Hypereutectoid Case, 200 Diameter
Normal Steel

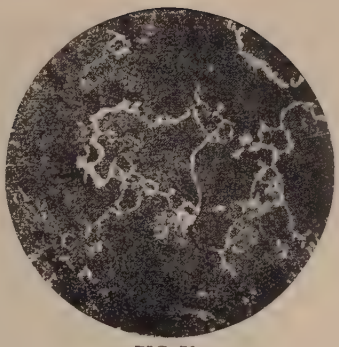


FIG. 73
Hypereutectoid Steel, 200 Diameter
Mixed Normal and Abnormal

FIG. 74
Hypereutectoid Steel, 50 Diameter
Mixed Normal and Abnormal Steel

FIG. 75
Hypereutectoid Case, 50 Diameter
Almost Normal

FIG. 76
Hypereutectoid Case, 50 Diameter
Abnormal Steel

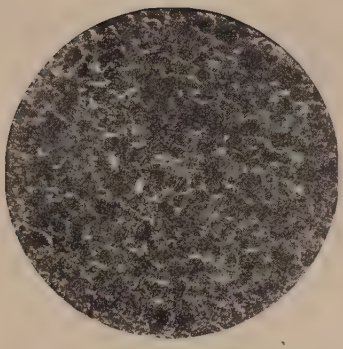


FIG. 77
Hypereutectoid Case, 200 Diameter
Abnormal Steel

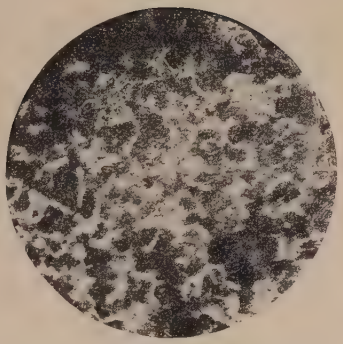


FIG. 78
Hypereutectoid Case, 200 Diameter
Very Abnormal Steel

When a steel has not been properly deoxidized in the making, and, therefore, contains an excessive amount of dissolved oxides, the iron carbide formed in the carburizing process is difficult to dissolve, with the result that on slow cooling the cementite of the hypereutectoid zone, instead of forming a network of cementite around grains of lamellar pearlite, separates out as heavy ridges of cementite in a matrix of ferrite, the pearlite of this zone divorcing to form free ferrite and cementite. This represents an extreme case of poorly deoxidized steel, there being all conditions down to the normal condition. Figs. 70, 71 and 72 represent structures in a normal steel, whereas Figs. 73, 74 and 75 show a mixed structure, both normal and abnormal. Figs. 76, 77 and 78 illustrate the structure of an improperly deoxidized or abnormal steel.

As the amount of dissolved oxides decreases the divorced pearlite decreases, and the cementite is more inclined to form a network, with more lamellar pearlite formed.

Small, curly, but numerous ridges of excess cementite, indicate that the steel is of poor quality, while a continuous network of cementite around pearlitic grains which are as large as the long heating at high temperature would lead one to expect, are evidences of well made steel.

There is also evidence that in a poorly finished steel the normal grain growth is much retarded, and the grain size of the core and case is very little changed by the long and high heating.

It is assumed that the presence of a large amount of dissolved oxide, etc., forms nuclei, which prevent large grain growth and result in the formation of many small grains when cooling through the critical range with consequent precipitation of the cementite.

When the cementite is as shown in Fig. 76, the martensite formed becomes very unstable and it is almost impossible to so cool the piece that troostite or even sorbite will not be formed. This, therefore, means that if the steel is not properly made and deoxidized, it is almost impossible to carburize and harden it so that troostitic or soft areas will not be obtained, and conversely if the pearlite of the hypereutectoid zone obtained by carburizing and slow cooling tends to divorce, then the steel is of inferior quality, and should not be used for case hardening any work of importance.

At the Timken Roller Bearing Company, who operate their own electric furnace steel plant, the steel used, whether made by themselves or purchased from other steel mills, is subjected to this check, with the result that a good quench means case hardened work free from all suspicion of soft areas or irregular case.

It cannot be stated too strongly, therefore, that for work of any importance the most important factor to be considered is the quality of the steel, and since deoxidation is of such importance, electric furnace steel, as generally made, is satisfactory, but in making basic open hearth steel for carburizing, extraordinary efforts must be made to obtain satisfactory results.

By simply carburizing a piece so as to form an excess of cementite in the hypereutectoid zone, and allowing the piece to cool slowly, it becomes possible to check a steel

for carburizing before using, and, if necessary, divert it to other uses.

It has been found that different parts of basic open hearth heats check differently, and that the single test is only an indication, since the deoxidizers, which are added in the ladle or just before tapping a heat that contains an excess of oxides, may not thoroughly act on the oxides when the steel is poured into the moulds.

Poor quality steel is generally the cause of soft spots, irregularity of martensite depth, and variation in the appearance of fracture after hardening.

It should be noted that a poorly made steel generally produces a case which is, after quenching, very fine grained but variable in depth, and generally containing soft spots.

It is also less affected by overheating in the hardening than is good steel, since the presence of dissolved oxides tends to prevent grain growth.

The carbon content of steel to be carburized should not run above 0.25%, and perferably not over 0.22%, with a low limit of 0.10%. Steel with a carbon content over 0.25% is likely to be unduly affected by its exposure to a high carburizing temperature for a considerable period, and may give a brittle product. The use of steel with a carbon content below 0.10% is likely to cause machining troubles.

The manganese content may run as high as 0.80% with safety. Usually a somewhat lower maximum is specified. High manganese will give greater strength in the core and better wear-resisting properties in the case than a steel of lower manganese content if properly carburized and treated. However, high manganese is apt to increase the brittleness of the core, induced by long heating at high temperature, especially in the presence of high silicon.

The standard steel used calls largely for .30% to .60% manganese. There is no reason why a lower content

could not be used, except that it sacrifices some core strength.

The maximum phosphorus content should not exceed .05%, and preferably should be below .04%. High phosphorus in carburized parts tends to give a steel that is brittle and poorly resistant to shock.

The maximum sulphur content should not exceed .05%. Sulphur segregations tend to produce soft spots, causing uneven heat treatment.

Silicon has no appreciable effect upon the physical properties of carburized parts if within the limits met in most commercial steels. High silicon, over .30%, especially in the presence of high manganese, causes brittleness.

It might be well to mention other elements which are not considered impurities, but, rather, are used in making alloy steels. The effect of certain alloys on the rate of carburization is rather interesting. Manganese, tungsten, chromium and molybdenum accelerate the rate of penetration, and also increase the concentration of carbon, while nickel, silicon and aluminum retard it. It is interesting to note that the former elements form double carbides, while the latter are present in steel as solid solution in the ferrite.

The alloy steels most commonly carburized are nickel, chromium and vanadium steels.

Nickel steels do not permit such rapid absorption of carbon as a plain carbon or a chromium steel, but the carbon is more evenly distributed, which helps to eliminate exfoliation. In addition, nickel steels are not as likely to be made brittle by long exposure to high carburizing temperatures. They are thus better able to withstand shocks. This fact also simplifies the subsequent heat treating operations. By the use of special compounds (mixed cements), it is possible to obtain equally good, if not better, penetration and concentration of carbon than with plain carbon steels. Lower carburizing heats can be used, due to the lower location of the critical range in nickel steels.

Certain steels of high nickel content—4% to 7%—can be carburized and air cooled. This operation gives a tough core, leaving the case in a martensitic condition, and eliminating necessity for further heat treatment.

Chromium increases the rate of absorption of carbon over that of plain carbon steels, and also gives a higher concentration of carbon in the case. Chromium steels, however, are sensitive to prolonged heating at high temperatures, and for that reason must always be given a double treatment. Proper carburizing and heat treating of chromium steels amply repays, in that they give an article with a tough core and an exceedingly strong, fine-grained and wear-resisting case.

Chromium-nickel steels, which are much used for carburizing, seem to possess many of the virtues of chromium and nickel steels without their respective bad points. They carburize as rapidly as plain carbon steels and give a more uniform and better graduated case. They also give a non-brittle, shock-resisting core after the carburizing operation and respond well to heat treatment.

Vanadium, in the amount present in commercial alloy steels, has little direct effect upon the carburizing process itself. However, it tends to give the steel finer and denser structure because vanadium, in itself, tends to act as a deoxidizer and, therefore, helps to remove difficulties on this score. This increases the dynamic strength appreciably, and decreases the effect of high and prolonged heating on shock-resisting properties. It also tends to widen the range of temperature within which good results may be obtained by quenching and drawing.

The uniformity of the heat to which parts to be carburized are subjected has considerable effect on the finished product. A fluctuating temperature causes an excess of coarse cementite crystals. A high heat leaves a distinct line of demarcation between the case and core. These defects cause spawling and flaking, especially in parts subjected to wear. Excess cementite needles or envelopes

surrounding crystals, commonly known as freckled edges, are very likely to give trouble on parts to be ground, causing the so-called grinding cracks.

The carburizing temperature and its uniformity controls the degree of carburizing.

While the theory has been advanced that carburization may take place at temperatures below the critical range, experience has proved that the low temperatures are very unsatisfactory for commercial work. The slight carburized zone obtained at a temperature of 705° C. to 788° C. (1300° F. to 1450° F.), with the ordinary grades of carburizing steels, is lacking in uniformity, low in carbon content, and with little graduation.

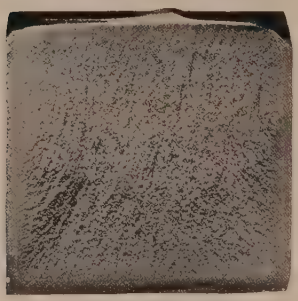


FIG. 79
Depth of Penetration
Carburized twenty-four hours at 874° C. (1605° F.)

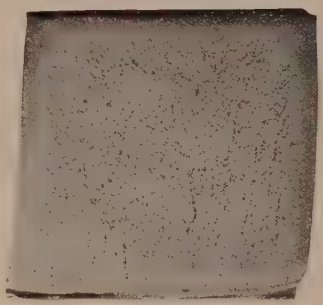


FIG. 80
Depth of Penetration
Carburized twenty-four hours at 925° C. (1697° F.)

There are a few special steels, however, principally the chrome vanadium steel, which absorb carbon quite readily at low temperatures.

The carburizing temperature is dependent upon the carburizing material used, inasmuch as some materials will give a .90% case at 871° C. (1600° F.), 1.05% case at 899° C. (1650° F.), 1.15% case at 927° C. (1700° F.), while other materials may give a .90% carbon case at 927° C. (1700° F.).

It is absolutely necessary to be thoroughly familiar with the carburizing material, the results obtained at certain heats, length of time required to obtain a certain depth of penetration at that temperature, and whether the heats used will injuriously affect the steel.

A temperature of 899° C. (1650° F.) is best for most purposes, taking into consideration the demand for quick carburizing, with retention of the physical properties of the steel.

FIG. 81
Depth of Penetration
Carburized twenty-four hours at 1010° C. (1850° F.)

The carburizing temperature influences the depth of penetration. The higher the temperature used in carburizing, the greater the depth of penetration, as shown in Figs. 79, 80 and 81. Fig. 79 represents a piece of steel carburized for twenty-four hours at a temperature of 874° C. (1605° F.), and shows the least penetration, whereas the piece carburized for twenty-four hours at a temperature of 925° C. (1697° F.), Fig. 80, shows a decidedly deeper penetration of case, and Fig. 81, which was carburized for twenty-four hours at a temperature of 1010° C. (1850° F.), gives the deepest case of all.

In hastening the carburizing operation the furnaces may be heated to 50° F. above the carburizing temperature until the pots are heated throughout, and then lowered to the correct carburizing temperature.

In commercial work, however, there are so many things to be taken into consideration that we think it best to summarize the effects of the temperature and thus allow our readers to make their selection.

As a further aid to the hardener, the specifications of the American Society of Automotive Engineers are given at the close of this treatise. It will be seen that the general characteristics are given, together with the heats for carburizing and heat treatment. These heats are approximate, but in very close range for proper refining.

THE DEPTH OF PENETRATION

The depth of penetration in a given time, as well as the carbon content or percentage of carbon in the carburized zone, is governed by the temperature used in carburizing and the length of time the work is held at the carburizing heat.

The higher the temperature used in carburizing, the greater the depth of penetration and the higher the carbon content of the carburized case, all of which has been proved by tests made by heating the same work under the same conditions, but increasing the carburizing temperature for each new heat or test.

The lowest temperature at which uniform penetration can be obtained is about 816° C. (1500° F.).

Work which is not "subjected to shock," but requiring the greatest wearing surface, can be carburized at a temperature of 927° C. (1700° F.) with a suitable carburizing material to obtain a carburized case of hypereutectoid composition of 1.15% carbon, as shown in Fig. 82.

The photo-micrograph shows the black areas as pearlite, and the white areas surrounding the pearlite as excess carbide or "free cementite."

The microscope plays an important role in determining the depth of the carburized case and also the carbon content of the case. It is possible by microscopic examination of steel, which has been annealed and cooled slowly, to

determine the percentage of carbon. The carburized case can be divided into three classes:

First, the hypoeutectoid layer, in which the amount of carbon is less than .85%, as shown in Fig. 83.

Second, the eutectoid layer, containing .85% to .90% carbon, as shown in Fig. 83.

Third, the hypereutectoid layer, in which the amount of carbon exceeds .85%, as shown in Fig. 83.

FIG. 82

Dark Areas, Pearlite. White Lines, Excess Carbide or "Free Cementite"

Dr. D. Hanson and J. E. Hurst, of England, found that excess cementite could be eliminated by carburizing at a temperature of 1700° F. for, say, five hours, at the end of which time there is a high concentration of carbide in the outer portions of the case. The temperature is then slowly reduced to 1550° F. and maintained at this temperature until the proper depth of case is obtained. It

was found that this method requires a few hours longer time on a ten-hour run to give the same depth of penetration as obtained at 1700° F., but a carburized case was obtained which was free of a network of excess cementite.

The trend of present practice is to use as low a carburizing heat as possible. A lower heat produces a less detrimental effect on the steel and makes the subsequent heat treatment easier. The average temperature used in commercial practice is 1650° to 1700° F. Low heat also tends to blend the case and core.

The nature of the atmosphere of the carburizing chamber has its effect not only on the process, but on the pots used, especially if of iron or steel. With a rich or reducing atmosphere there is much less material actually burned up, even with poorly sealed pots, than with an oxidizing atmosphere. Running with an oxidizing atmosphere is also a waste of fuel and adds cost to the carburizing process.

At a given heat within the range used normally in practice, the effect of the length of the carburizing action after the first few hours, is to increase the depth of carburization without appreciably increasing the concentration of carbon. This holds true with any commercially practical carburizing compound.

In the average practice of carburizing, however, it is best not to depend upon timing the operation to determine its completion, but rather to take test pieces from one or more pots to determine the actual depth of penetration. The depth can be judged by hardening the fracture, regulating the hardening so as to show as much differentiation between the case and core as possible. Heat tinting or bluing of the fractured piece is helpful. The Brinell microscope is also used for making uniform measurements on commercial work. The fracture test, however, is very likely to be deceptive, and for that reason polishing and etching is recommended, or at least the etching of the fracture. The etched sample can then be examined by the

Carburized Case of
90-Point Carbon

Graduation of Carbon From Case Into the Core
Magnification, 100 Diameters

FIG. 83

naked eye or under a microscope. The fracture of a hardened piece etched in a 15% solution of nitric acid will develop the case very clearly.

Depth of case can be controlled by timing, however, if sufficient preliminary work be done, such as determining the heating time of the pots and contents, and the exact time and temperature combination for the particular product to give the proper results. By plotting a time temperature curve and following it exactly, the taking of tests can be avoided, providing the compound and steel remain uniform.

Conditions in working, cost of hardening, haste for parts needed in production, etc., necessitate that the practical man make a close study of his work. Results, while not carrying the steel to the highest degrees of hardness, but sufficient for present needs, can be obtained by a close study of the effect of high carbon case, light or thin penetration, quenching directly from the carburizing pot, or allowing the work to cool in the pots and reheating to the hardening temperature.

The above methods are used by many hardeners, knowing that they are not obtaining the greatest efficiency in the piece treated, but time, conditions in the shop, and the cost of products are the excuses for hastening or changing the method to obtain the best possible results, such as cooling in the carburizing pot and heating for core refinement, heating for case refinement, and drawing, if necessary.

A carburized case of great depth and high carbon content may cause warping, cracking and brittleness on small parts, while a thin, low carbon case is of no value to the work other than the benefit the piece receives from the heating and quenching.

The selection of the best carburizing temperature to obtain uniform work of the highest standard requires consideration of the composition of the steel to carburize, shape of the boxes, fuel, cost of production, etc., all of

which we can touch lightly, leaving much to the judgment of the individual to regulate conditions under his control.

The packing of carburizing boxes is an important item in the carburizing process. In brief, parts should be so packed that they are always in contact with carburizing material and never in contact with other bodies. Sufficient material should cover the articles to prevent exposure during this process.

Pots are generally packed while sitting on the heat-treatment department floor. Specially constructed benches with handy bins for work and carburizing compound, make this operation much easier for the workers.

Dumping the pots after the operation is finished is usually a disagreeable job. A large percentage of the work is cooled in the pot. A device that works well for the dumping operation is patterned after the rotary ash sifter, but with screens of three different sizes of mesh, one catching the work, one the scale, and one the compound, while the dust drops through the finest sieve and is thrown away. A dust collector takes away any fine particles suspended in the air.

Another important item is the mixing of the old material with new. This mixing should be thoroughly done, and at the same time care should be taken to avoid crushing the compound or increasing the percentage of fine material.

After the carburizing operation has been completed, the next step is the heat treatment of the articles carburized.

Heat treatment of carburized parts is carried on according to the specific purpose for which the parts are to be used.

For unimportant parts, requiring a hard surface only and not needing shock-resisting properties, it has been customary to quench directly from the carburizing pots. This method has been modified by permitting the product

to cool in the pot, reheating, and quenching at a temperature sufficiently high to refine the case.

In all other instances it is customary to cool in the pot.

Articles that must resist shock are given a double heat treatment, consisting of a quench from a high temperature to refine the core, followed by a lower quench to refine the case. These operations are sometimes followed by a drawing operation at a lower heat (about 400° F.), which tends to relieve strains set up between the case and core.

Just as much careful attention and skill should be applied to heat-treating carburized articles as in treating parts made from a high carbon steel. The treatments of such parts are too often neglected.

The design of parts to be carburized should be watched carefully. Sharp corners should be filleted, thick and thin sections adjacent to each other should be eliminated as much as possible, and thin sections avoided as much as is consistent with the elements of good design.

Articles with scaly or dirty surfaces should not be carburized until cleaned.

METHODS BY WHICH THE CEMENTITE NETWORK MAY BE AVOIDED

Methods which suggest themselves for preventing the formation of an excess of cementite in the harmful form of a network may be:

(a) Methods by which the excess cementite, once it is formed, is distributed by suitable treatment in a less harmful manner.

(b) Methods of case hardening in which the process is so arranged that a serious excess of free cementite is never formed.

The methods which come under classification (a) may consist of:

1. The prevention of the separation of the cementite as

a network in the steel at any time by quenching the articles direct from the carburizing box. Slow cooling through the critical range is essential to the formation of a network, and if the material be quenched in the first place from the case hardening temperature, this separation can never occur, while the subsequent treatments to which the articles are submitted are such that the method of distribution of the carbides does not become harmful. In many cases this method is difficult to apply in practice, especially where a number of intricate parts must be treated in the same box. The method of tipping the whole contents of the box into water is hardly practicable where freedom from distortion is necessary, while in the case of nickel steels, which should be quenched in oil, the difficulties are still further increased. The method of quenching from the boxes is practicable and useful in a number of cases, but it must be remembered that it can in no way replace the refining treatments, and must be considered as a preparatory operation only.

2. Reheating the article, after cooling, to such a temperature, probably the carburizing temperature, that all the cementite becomes redissolved, followed by quenching. This process is in some ways better than the previous method, in that it is under better control, but it involves an additional treatment in a process which is already lengthy, and is likely to find little favor on that account. It also offers undesirable opportunity for surface oxidation of the case and increases the amount of distortion.

These methods are identical in principle. They ensure the retention of the excess carbide in solution in the austenite, from which it is only precipitated during subsequent operations in a harmless "globular" form.

Methods which come under the heading (b), and which may be described as preventive measures, include:

1. The use of a less vigorous cement.—If the reaction between cement and steel be slow, then the normal rate of diffusion may remove the carbide into the steel at a

sufficiently rapid rate to prevent the eutectoid composition being reached on the surface before the required thickness of case is obtained. The use of a gaseous cement, or the method of isolating the cement from the articles to be carburized, as suggested by Giolitti, would appear to be applicable, and the author believes that these methods have been used with success.

2. By the regulation of the temperature during carburization in such a manner that excessive carbide concentration is not obtained.—This method seemed to the author to offer many advantages if only it were possible to apply it without increasing the practical difficulties or unduly prolonging the operation. In this effort they have, they think, been entirely successful.

It is evident that a case of approximately eutectoid composition may be obtained by carburizing with a fairly vigorous cement at a temperature only slightly in excess of the eutectoid point, but it is equally evident that such a method is far too slow to be practicable on a large scale. The method which has been adopted does, however, possess practically all the advantages of the slow method indicated above, without being markedly slower than the methods ordinarily in use. It consists in but a slight modification of existing methods. The box containing the articles is placed in the furnace, and the carburizing operation is carried out, as in existing practice, for a period sufficiently long to obtain a depth of case somewhat less than is desired in the finished article, and the author has found that one-half to two-thirds of the final depth is in most cases satisfactory. The temperature of this operation is usually about 900° C., and while it is in progress an appreciable excess of carbide over the eutectoid composition is absorbed in the outer portions of the case. The temperature of the furnace is now reduced slowly over a period of several hours—to a temperature which is not greater than the refining temperature to which the articles will subsequently be submitted, and is now lower than the eutectoid temperature of the

steel. The box is maintained at this temperature for some time, and is then removed from the furnace and allowed to cool in air.

The effect of the period of slow cooling on the distribution of carbide in the case can readily be seen. As the temperature falls, the solubility of the cementite in the austenite of the steel becomes progressively lowered; those portions which were saturated, or nearly saturated, with carbide at the case hardening temperature, tend to throw out their excess of cementite, and those containing less carbide tend to approach more nearly their saturation point. Consequently, as cooling continues, carbide must be removed from solution in the outer portions, either by deposition of cementite, or by some other means. Now it is clear that, during this period, diffusion of carbide towards the center of the mass is able to continue, and the only condition that must be fulfilled in this operation is that the rate of cooling be sufficiently slow for the removal of the carbide by diffusion towards the center, to be sufficient to prevent super-saturation of the case, at any moment, with the precipitation of free cementite—a matter which is very easily determined by one or two trials.

It is equally clear that during this period little or no additional carbide will dissolve in the austenite of the steel, for such absorption can only take place as and when the austenite becomes unsaturated with respect to cementite; that is, as the cementite diffuses into the mass. The internal equilibria in the steel are such that they tend to adjust themselves without any considerable influx of additional carbide. The continual tendency for the case to become super-saturated as the temperature falls renders it less able to absorb more carbon, while the counteracting tendency of diffusion into the core, which determines to some extent the rate at which carbide is absorbed, is partially satisfied by the reduction of the concentration in the case itself. The period of falling temperature, therefore, is one in which the main reaction is the more uniform

distribution of the carbide which has already been dissolved in the case during the preliminary heating at the higher temperature.

The final temperature in this treatment is of importance, since it largely determines the maximum concentration of carbide which can exist in the case at the end of the operation, and where the concentration in the finished case is required to be approximately that of the eutectoid, the final temperature should approach fairly closely that of the eutectoid transformation. If, however, the final temperature be lower than that at which the refining treatment is to be carried out, and the cooling to that temperature be sufficiently slow, there should not be left in the case an amount of cementite which will not be wholly dissolved during this refining treatment, and the presence of a network in the finished product is impossible.

It is evident that the exact times and temperatures can best be determined for each class of articles by trial, but as this is short and simple, it need give no trouble.

The author has not taken into account the production of excessive cementite concentration through oscillations in the case hardening temperature, because he wishes to show that this excess may be produced, especially in nickel steels, when accidental variations of this kind are not present. In any case, the method of using a falling temperature for the final stages of the carburization is probably the best which could be adopted for removing the excess produced in this manner.

CHAPTER XVIII

CARBURIZING MATERIALS

Carburizing compounds are manufactured in granular and pellet form of various meshes. The fine mesh compounds have their advantages under certain conditions, but the coarse—approximately No. 6 and No. 4 mesh—is most generally used.

The composition of the carburizing material is very important, especially its carbon content. The carbons most generally used are bone, charred leather, wood charcoal, petroleum coke and gas-house coke, which are usually compounded with energizing chemicals to increase the amount of carburizing gases in the carburizing process.

The charred bone and charred leather are the best forms of carbon. The grains are cellular and porous, thus more readily combining with the oxygen in the air in the pots. It is also more readily acted upon by the energizing chemicals. Then, again, these two forms of carbon contain nitrogenous elements which act as energizers increasing its carburizing value.

The amount of carbon present in a carburizing material means nothing so far as the carburizing value is concerned unless the carbon is of such a form or is treated in such a manner that it will readily liberate its carburizing gases.

A fairly rapid heating of carburizing material may, in some instances, be desirable but it is by no means essential. The rate of penetration of carbon in any grade of steel is normally governed by the temperature used in carburizing and the carburizing gases liberated by the material at the carburizing temperature.

The effect of increasing the temperature is to increase the solubility of the carbon in the steel.

All carburizing mediums do not give the same rate of penetration at the same temperature; charcoal and coke are not so rapid as leather, bone, and other compounds rich in hydro-carbons.

The freedom with which the carburizing gases are liberated depends entirely upon the composition of the mixture and the form in which the carbonaceous material exists. It is generally conceded that carbon monoxide is the true carburizing gas, and is developed from solid carburizers by the influence of heat—indirectly from the decomposition of hydro-carbon vapor and cyanogen and directly from the oxidation of the fixed carbon. The hydro-carbons and cyanogens are much more easily volatilized by heat than the fixed carbons, which are more graphitic in their nature, especially those of mineral origin.

A compound may thus have a high heat conductivity and yet, being composed largely of fixed carbon, will not liberate and form the carburizing gases in any quantities until the higher temperatures are reached. It is not correct, therefore, to assume that all carburizers are equally efficient in their rate of penetration at any one temperature, whether that heat is 816° C. (1500° F.) or 927° C. (1700° F.).

One point necessary in case hardening is absolute control over the carburizing temperatures, especially if the work is to be subsequently heat treated. Under such conditions the carburizing heats must be carried as close to the critical range of the steel as possible, and yet give a satisfactory case. If this were not essential, carburizing temperatures could be carried to 1038° C. (1900° F.), and even above, and the time materially shortened.

The effect of high temperature on steel is a coarse granular structure which is refined only with the greatest difficulty. This is especially true on case hardening work, as it is difficult to refine the core, and the high heat required for this renders the high carbon case exceedingly weak and brittle with a tendency to chip.

Case hardening does not improve the quality of the steel under the most favorable conditions, and the hardener knows it is better never to overheat the metal than try to restore an overheated condition.

To prevent this overheating, therefore, expensive installations of pyrometers are used in connection with the furnaces, and much care is taken that no variations in the carburizing temperatures occur.

The mere adding of energizing chemicals to grains of carbon will not produce a carburizing compound which will give satisfactory results of uniformity. This is due to the fact that the chemicals do not bind to the surface of the grains of carbon, and tend to sift to the bottom of the shipping package. Therefore, if you take a portion of such material from the bottom of the package, entirely different carburizing results will be obtained than with material taken from the top of the package.

It is the experience of many manufacturers that it is impossible to manufacture a carburizing material which will give uniform commercial service until the energizers are attached to the grains of carbon either by impregnating the grain or binding the same to the grain by means of a binder.

The most uniform results are obtained from a carburizing material made of grains of charred leather and wood charcoal impregnated with energizing chemicals, then coated with a binder, and finally coated with a mixture of pulverized charred leather, charred bone and energizers, and then baked. This material, when first used, will char the binder which will hold all the energizer fastened to the grains, thereby producing uniform results, and adding carburizing life to the compound.

If the carburizing material is not properly manufactured the result is very expensive owing to the lack of uniformity in the results obtained in commercial use.

Carburizing materials made wholly of gas-house coke or coal have a tendency to support internal combustion.

The carburizing material in the pot burns to a higher temperature than the furnace, which causes freckled corners on the surface of the steel, which are almost impossible to refine. This is due to the fact that carbons of this nature require so much energizer to liberate the carbon gases that a general combustion results unless great care is exercised with their use.

The selection of the proper carburizing material for the particular class of work is important and requires consideration. Some manufacturers claim that one product can be used for all classes of work, but this is not true.

For work in which the carburized case when heat treated must withstand tremendous pressure and wear in service, such as is required of ball and roller bearings, it becomes necessary that the carburizing process be kept under the greatest possible control. Also in work of this character when a great production of relatively small parts is to be handled, the depth of case and characteristics of the case in each and every piece in a given furnace charge must be held within very close limits.

In order to meet these conditions a compound is required which is relatively very slow, so that the time required to bring the work to heat is a small percentage of the total time necessary to obtain the case depth desired. By this means all pieces are carburizing for practically the same length of time, and the variation in case depth for pieces in the same box is very small.

For this purpose charred bone, or charred bone charged with hydro-carbon oil, is best suited, since without the use of energizers a carbon depth is obtained in from fourteen to fifty hours, which is suitable for almost any class of work.

The use of a slow compound, such as charred bone, has also the advantage that with it, relatively large containers can be used, which is an advantage when the production of the same size article is large, since with them the furnace load can be increased and department investment for furnaces, boxes, etc., is smaller.

On the other hand, when the depth of case and the presence of excess cementite is not of the greatest importance, and where the limits of variation of case depth and carbon content can be made relatively wide as in most commercial carburizing, as is needed for axle shafts, agricultural implements, etc., then a compound can be used which gives the greatest depth of case in a given time. Here, however, the containers and furnaces must be small to insure rapid penetration of the heat and when using a highly energized compound; but even with small boxes and furnaces it is difficult to avoid irregularities in the results.

It can be seen readily that there are certain conditions which require a given class of compounds, the cheaper and less important jobs being satisfactorily accomplished with a highly energized material in four to six hours at 1750° F., while the expensive and more important parts require twenty-four to forty hours using a bone base with no energizer, and for intermediate conditions there are intermediate compounds.

In choosing a compound it is necessary, therefore, to determine what are the limits of case variation allowed, and then to check various compounds with care, being extremely careful to note the variation in case depth and carbon content in various parts of each box and in all parts of the furnace.

If the results obtained are not satisfactory it may be necessary to decrease the amount of energizer and increase the length of time to obtain a given depth or vice versa.

The carbon content of the case can best be regulated by the operating temperature, the percentage of carbon being less at a given temperature for bone base compounds with little or no energizer than with energizer compounds.

It is possible even with bone to obtain a high carbon case of 1.25% and over if the temperature is, say, 1750° F. to 1800° F.

As the temperature increases the bone compounds be-

come more rapid, and the carbonate compounds become less rapid, both classes having about the same speed at 1850° F. The high temperature has the effect of driving off all the available CO_2 from the carbonates, with the result that in some compounds which contain no bone, leather, etc., at 1850° F. it is possible to obtain a decarburized case.

As the temperature increases above 1850° F. the rate of diffusion is equal to and finally greater than the rate at which the carbide is formed, with the result that at 2200° F. and over the carbon content of the surface is generally eutectoid or less, depending somewhat on rate of cooling.

Charcoal base compounds with carbonate energizers are most active at from 1600° F. to 1700° F.

Bone base compounds are most active at the higher temperatures, the rate increase in depth for these compounds being almost directly proportional to the increase in temperature.

It is true that one can take an energized compound and in an experimental way obtain a carburized case of eutectoid or .85% carbon by lowering the carburizing temperature, but when applied in practice a slight elevation in the carburizing temperature, etc., will tend to pile up the carbon and cause excess cementite or brittleness.

It is also unadvisable to use a material of this nature for carburizing copper-plated work, which is to be local hardened, inasmuch as energizers have a tendency to penetrate the copper and carburize the steel.

The material should be of such a composition that it will produce a certain amount of carburizing gases and at a uniform rate of speed.

The material should not readily exhaust its carburizing value, but should be suitable for repeated use, especially if a certain percentage of new material is added each time.

The material should not contain a large amount of sulphur-bearing material.

It should not show excessive shrinkage in volume or weight, especially the former. Shrinkage in volume should not exceed 15%.

Internal combustion should be absent.

Granular or pellet form material should be free from dust or inert material.

The actual physical strength of a compound, especially when heated, is important, in that it determines the supporting power of the compound and the liability of parts to distort when packed in it.

In selecting a material for a given problem the requirements of the finished product should be taken into consideration. Depth of case and hardness required, resistance to shock, wearing quality, design of articles to be carburized, and subsequent operations necessary are all items that should be given consideration.

A material that becomes exhausted quickly may ultimately cost more than one whose first cost is high, but which has a long life. In materials containing an energizer, the life depends a great deal upon the ability of the material to regenerate.

However, it does not follow that coarse and porous material is more efficient in its penetrating power on the steel than the solid and powdered materials.

The value of a carburizing agent also depends upon the kind of gases developed by the heat applied.

Some materials give off oxidizing gases, which oxidize the carburized work and result in that condition known as surface decarburization.

We have known of several instances where all the steel carburized in one heat would not harden by quenching, even after the carburizing operation was repeated, yet the broken part showed a good depth of case. Cuts were taken from the outer layer, and upon analysis showed a surface decarburization to a depth of .008 of an inch and a carbon content of .56%. The second cut of .01 inch gave a

carbon content of .86%. Figs. 84 and 85 indicate a decarburized condition very plainly.

Usually decarburization occurs only with a weak carburizer and at low carburizing temperatures.

Surface decarburization never occurs when a reducing atmosphere is maintained by the presence of hydro-carbon gases. This point is mentioned because the materials, such

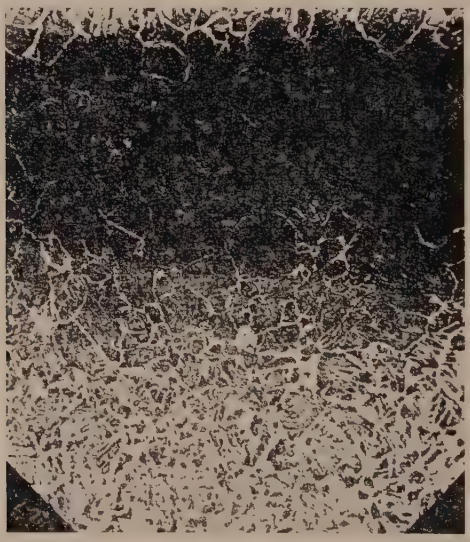


FIG 84
Case Carburized, 50 Diameter
Decarburized Edge

as bone, etc., showing slow heat conduction, are rich in hydro-carbons, while in the materials with the greatest thermal conductivity, the hydro-carbons are entirely lacking.

The presence of free cementite in quantity is due either to too high a temperature in carburizing or to the character of the carburizing compound.

It gives rise to cracks and brittleness, and, further, brittleness is not limited to the case, but extends to and through the core.

This is a cause of freckled corners and may be detected by the coarse fracture of a broken section.

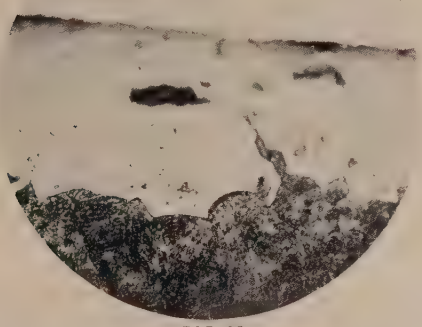


FIG. 85

Photo-micrograph Taken at Edge of Specimen Showing Decarburization, and Manganese Sulphide. Etched in a 4% Solution of Nitric Acid and Alcohol X 500

The carburizing material should be kept dry, as moisture tends to pit the work and to cause soft spots.

Pipes of suitable diameters can be used for carburizing cam-shafts, spindles, etc.

The case of all work to be ground after carburizing should possess a carbon content above .90%, otherwise it will be ground below the carbon point, which gives the hardest possible surface. This is often the cause of soft spots in carburizing.

All carburizing material should be kept clean. The time is well spent in removing iron scale and fire clay from the carburizing material, as these foreign materials cause soft spots.

CHAPTER XIX

CASE HARDENING WITH CYANIDES

The process of case carburizing or case hardening, as it is more often called, is one of the most valuable gifts which science has given to the metallurgical industry, but like many other processes connected with the treatment of iron and steel, the exact laws governing the phenomena which occur are still not altogether known, and much more research must be completed before we can definitely state that we are cognizant of all the facts relating to the different reactions that take place. While much valuable research on the subject has been done, the industrial application of the principles involved is still accompanied with probably more empiricism than any other process, due perhaps to the somewhat abstruse and difficult nature of the underlying laws, and also to the fact that many of the results are still the subject of much controversy. The truth of the latter statement is particularly applicable to our rather scanty knowledge of the action of the cyanogen radical (CN) on iron and steel.

It is with the purpose in mind of giving a brief resumé of the more important theories regarding case carburizing with cyanogen compounds with the particular view in mind of showing some of the effects of the element nitrogen on the structure and the consequent changes in the physical properties of the article undergoing treatment that this article was written.

It is not within the scope of this treatise to go into the actual methods of case hardening with cyanide as practiced in the industry, as they consist in general in heating the articles to be case hardened in a bath of the fused salt which is to act as the carburizer. It is thought, however, that many of the irregularities which arise during the

process may be overcome if a clear understanding of the theory is known.

The physical chemistry of the metallurgical reactions involved has been thoroughly investigated by:

1. R. Schenck: The Physical Chemistry of the Metals, translated by R. S. Dean.
2. A. Portevin: Revue de Metallurgie, 1910.
3. A. Matsubara: Chemical Equilibrium between Iron, Oxygen and Carbon: Transactions of the American Institute of Mining and Metallurgical Engineers, February, 1921.

Some of the fundamental reasons for the phenomena about to be outlined may be found in the works of these men, explained in much greater detail than the scope of this book permits.

Not being concerned with the temperature below which iron is in the gamma state (when the carburization of iron will not take place), no mention of the equilibrium systems in the lower temperature ranges will be made. The reaction of carburization accepted by most authorities as being fundamental in the cyaniding process (which may be described as an equilibrium system of cyanogen, nitrogen, and carbon), is

$$2(a)CN+6Fe=2(a)+2Fe_3C+N_2$$

This reaction is reversible under certain conditions, as will be mentioned later; but as shown above is proceeding in only one direction which actually takes place when case hardening under normal conditions in commercial practice. The cyanogen liberated by the cementation bath and coming in contact with the piece being carburized, reacts as in the above equation forming the carbide of iron, nitrogen, and the metal of the particular cyanide used (usually sodium). That this takes place is shown by an experiment made by heating in an iron tube sodium

cyanide and iron.[1] The result was that the iron was carburized and that a quantity of metallic sodium was found in the colder part of the tube. In passing, it should be mentioned that there is, as recent research has shown us, a further reaction between the nitrogen set free in reaction and the iron of the piece being carburized. This is very important and affects the results in a marked degree. This phase of the question will be mentioned later.

For a long time it was thought that the nitrogen set free by the carburizing process (see reaction) did not affect the properties of the "case" obtained. In the light of more recent experiments, however, it would seem that the nitrogen thus liberated combines with the iron either to form a solid solution or a eutectoid (possibly between FeN and Fe). Brophy and Leiter found that when a bar containing 0.04% carbon was immersed in a bath of cyanide for four hours that the resulting surface analyzed only 0.33% carbon, yet it easily resisted a file. They also found that if the cyanide case be ground off that the rod was still very brittle and remained so even after annealing. Prof. H. Fay advanced the theory which was afterwards corroborated by Lieutenant Wheeler, that a sort of case hardening process took place in the erosion of guns, except that the hardening constituent instead of being carbon as in ordinary procedure, was the nitrogen introduced into the steel by the explosion of the powder. That his theory is correct is clearly shown in an experiment which he described in an article published in February, 1921.[2] "A round bar of low-carbon steel was heated in a cyanide bath for ten minutes at 830° C., and allowed to cool in the air. Successive layers, 1/200 inches in thickness, were turned from this bar and analyzed for carbon and nitrogen, with the following results:

[1] After Portevin.

[2] Chem. & Met. Engineering. February, 1921.

Layer No.	1	2	3	4
Thickness of concentric layers in succession from outside toward interior, inches	1	1	1	1
	200	200	200	200
Carbon, per cent	0.16	0.30	0.06	0.15
Nitrogen, per cent	0.57	0.201	0.155	0.027

It will be seen that the outside layer contains 0.57% nitrogen, which is indeed surprising when it is considered that this sample was treated for only ten minutes. The nitrogen progressively diminishes toward the center of the bar, but apparently penetrates at a slightly greater rate than the carbon."

More recent experiments by Ruder and Brophy[1] show that the presence of nitrogen can be detected in case hardened steel by the use of certain etching reagents, the most successful of which is Stead's (phosphorus) reagent. "When properly etched the ferrite is covered with copper, the cementite remains bright and the pearlite is also white. The nitride needles and the white (nitride?) hard constituent of the eutectoid patch are black. On further etching the pearlite also becomes copper plated, but the cementite remains white and the nitride etches out, and, in appearance, remains dark." The results of the experiments of these two authors, as well as those of other metallurgists clearly indicate that the case obtained by the use of cyanides (and as a matter of fact those carbon carburizing materials containing nitrogen) may be extremely brittle and due to the fact that nitrogen penetrates farther into the steel than carbon often renders the core hard and brittle.

The exact conditions which sometimes cause the formation of iron nitride (FeN) inside of the case proper are not clearly understood, but this condition is undesirable. It is very frequently found when pieces are exposed to the action of the cyanide bath for a considerable period of

[1] Chem. & Met. Engineering. November, 1921.

time for the purpose of obtaining a thick case. It should be distinctly borne in mind that the hardness obtained on any article case hardened by a cyanide salt is not due entirely to the increased carbon content of the case. Assume, for example, a case having a nitrogen content of .50% and a carbon content of .30%. Such a case will, upon quenching, give a martensitic structure and be very hard, in fact equal the hardness of a 1% carbon case in which no nitrogen is present.

It might be well with the theory as outlined above in mind to look into some of the difficulties which are met in carburizing practice with a view to preventing their occurrence.

Probably the most serious and most frequent difficulties which are encountered in the case hardening of steel, whether a cyanide bath or a carbon packing material is used, are cases which contain soft spots or irregularities in the hardness of the surface of the finished article, and cases which exfoliate or crack and spall off.

Soft spots are very apt to occur in material which has been case hardened in a cyanide bath. If the stock used in case hardening has any oxidized impurities therein, or a piece of scale or oxide is present on the surface, it appears that soft spots are much more likely to occur if the case hardening is carried out by means of a cyanide bath. When such stock is carburized in boxes and packed in the customary manner, the time of exposure to carburizing conditions generally is sufficiently long to overcome the effect of the scale or oxidizing inclusions which may be present. The time of exposure in a cyanide bath is generally much less. Certain conditions where scale has been imbedded in a piece may not cause trouble when the carburizing has been carried out in boxes with a carbonaceous packing, whereas soft spots will result if carburizing is done in a cyanide bath.

Steel which is very strongly banded is likely to give trouble regardless of the means of carburizing employed. In the second place, the necessity of uniform quenching

cannot be over-exaggerated, and it is fully as important with articles which have been cased in a cyanide bath. An article may have a case of the proper carbon content and of the proper depth, but if the quenching operation is not conducted with extreme care so that absolute uniformity in cooling takes place, soft spots are apt to result. An example of this was recently brought to our attention where wrist pins, fifty or a hundred in a lot, were being quenched in water and apparently the entire

FIG. 86
Heating Tray

mass was cooled uniformly. On closer examination, however, it was found that where the wrist pins touched together in falling to the bottom of the quenching tank soft spots appeared after grinding. It was found necessary, therefore, to provide a tray containing prongs on which each pin was placed during heating, so that when the plate was drawn from the furnace and turned over in the quenching tank each wrist pin struck the water separately. Fig. 86 shows the tray which was devised to overcome this trouble.

CHAPTER XX

CONTAINERS FOR PACK HARDENING

The container or carburizing box is a highly important factor in the process.

It must be of a size and shape that will lend to economical packing of the product to be carburized and of the carburizing compound.

The size must be carefully worked out to conform with the carburizing compound, and if the compound is highly energized and rapid, the box must be designed to heat up as uniformly and as rapidly as possible.

These conditions necessitate the smallest boxes consistent with commercial operation when using highly energized compounds, and since the corners of square and rectangular boxes heat more quickly than the rest of the box, it is advisable wherever possible to use a round pot.

Round pots are more easy to seal and less subject to distortion.

The thinner the metal the better, which constitutes a good reason for using the heat resisting alloys now on the market.

In order to obtain thin walled pots and boxes, care should be taken not to reduce too much the stiffening ribs or beadings which are necessary to reduce warpage.

Pots should carry legs at least two inches high to enable the heat to circulate under them. Legs are a necessity where pot trucks are used with a forked carrier which is run under the pots for moving them.

The sealing of the box or container is extremely important, due to the recognized fact that more of the actual carburizing action is brought about by the gases generated by the compound than by the solids of the compound. If

this can be confined, and especially if a pressure can be built up inside the pot, the carburizing action will be greater. In fact, some concerns are using their carburizing boxes upside down; that is, the lid of the pot is provided with legs and the pot is placed in the furnace accordingly with no luting necessary. This method not only prevents the carburizing gases from escaping, but also prevents the burning away of the compound and also produces a carburizing atmosphere in the pot even should the compound shrink beyond the work it eliminates; that is, oxidation or scaling.

However, it is rather difficult to construct a pot to withstand a very high pressure at carburizing temperatures. The general practice is to seal loose-fitting covers with a mixture of fire clay, sand, and water.

A type of pot which has proved superior to pots sealed with fire clay or steel chips is the machined cover, heat-resisting alloy pot. The pot and cover are so cast that they fit each other at an angle. The inside surface of the top of the pot and the rim of the cover are machined to fit each other, the cover fitting into the pot similar to a wedge. Neither the pot nor cover can change shape without both changing, and thus the tendency to warp is minimized. If the pot expands more than the cover then the cover slips a little further into the pot. This gives a fairly tight uniform seal on every pot. Pots of this type have increased the efficiency of the carburizing process 15% to 20%, at the same time giving uniform penetration.

The direct bearing which the container has on the cost of the carburizing operation as well as on the results obtained, cannot be overestimated. The use of any container which is subject to cracking, warping, or scaling, necessitates carrying a stock of containers, but more than this it means that any process involving their use is inefficient, consuming additional fuel, requiring additional labor, and limiting the output of the plant.

Cast iron, malleable iron, or steel is not the best material for containers which must withstand carburizing temperatures.

The rusting or scaling of iron and steel at room temperatures is such a common occurrence that it is never given a second thought. Yet this same material, which will not withstand the atmospheric conditions at normal temperature, is used in a process involving the maintenance of a temperature of between 1650° and 1700° F. What happens at room temperature is accelerated at carburizing temperature; the scaling that was superficial at room temperature is excessive and amounts to an actual growth at elevated temperatures. This scaling or growth of ferrous materials is unavoidable, and is beyond human control, being the natural result of the affinity of iron for oxygen.

The scaling of a container under furnace operating conditions is a serious matter. It not only means that the dimensions of the container have changed, but also that higher furnace temperatures are necessary in order to drive the heat into the contents of the container. Scale is refractory and is a poor conductor of heat. So with a pack hardening container the scale which always forms resists the ready penetration of heat.

The variations in carburizing time, made necessary by the formation of scale on the container, also produce non-uniform results from successive heats, since it is a matter of judgment what time will be needed to produce similar results.

If the scale, having once formed, would remain in position on the container, its refractory properties might be overlooked to a certain extent. Unfortunately, this is not the case, as the scale falls off, due to its different rate of expansion from that of the iron or steel from which it was formed. This constant falling away of the scale exposes fresh surfaces of the container to further oxidation, and ultimately causes the container to become so thin that it is no longer able to carry its allotted number of

parts, or else it is burned through and allows the carburizing meal to be burnt away.

Due to this constant thinning of the container it is essential that the container be originally quite heavy in order that sufficient material be present to allow for the reduction in wall thickness with each successive heat. This also means more weight per container to be paid for in the initial investment, and means more fuel to be consumed in heating this excess amount of metal.

FIG. 87
Carburizing Pot Scaled

The cracking of ferrous containers is expensive and causes much spoilage. Cracks tend to support internal combustion of the carburizing material in the containers, and oftentimes heat to a higher temperature than the carburizing furnace.

Heat-resisting alloy pots have been developed, composed principally of nickel and chromium, which give thousands of hours of service without scaling, warping, or cracking.

FIG 88

Packing Pots at the Timken Roller Bearing Co., Canton, Ohio, one of the Largest Users of Carburizing Material in the United States

FIG. 89

Unpotting the Parts at Timken Roller Bearing Co., Canton, Ohio

While their first cost is higher than that of iron or steel, the fact the carburized parts produced in them are of uniform quality throughout their long life, together with the facts that no luting is necessary, due to their design; that less fuel is required to maintain the correct temperatures within the container; that they are lighter than iron or cast steel containers, and are, therefore, easier to handle; that the carburizing compound can be used over again in greater percentages of old compound to new, and that the container never scales away, have resulted in their being adopted by many of the large heat-treating plants of the country.

Alloy pots to be satisfactory must be very carefully made and designed.

Most of the failures of the alloy pots have been due to poor foundry practice and insufficient stiffening ribs.

The improper gating of the molds, as well as heats poorly made in the alloy melting furnace have resulted in severe strains and segregations in the pots with their attendant cracking and burning out, and have caused the pots to be condemned.

In buying pots of this kind where the investment is large, care must be taken that the carburizing compound does not have a chemical reaction with the nickel or chromium of the boxes at high temperatures, and produce a pitting or corrosion of the metal which results in the failure of the box. Also great care must be taken that the carburizing pots have sufficient ribs to prevent warpage and cracking, due to inherent casting strains.

Pots with cored center are used for gears, ball and roller bearings and small parts so as to obtain the most uniform rate of penetration, as shown in Figs. 88 and 89.

The pieces should be packed at least ¼ inch apart and ½ inch from the sides of the carburizing pot. It is advisable to place 1 inch of carburizing material on top of the work under the lid of the pot to allow for shrinkage of the carburizing material.

Nickel chrome containers are also used for molten lead. For this purpose a solid, close-grained metal is supplied, which is non-porous, non-oxidizing and will not sweat lead. This metal is not attacked by the molten lead, and therefore, with reasonable care should last several thousand hours at the temperature of lead-pot operation; providing, of course, that the surface of the molten lead is well protected from the influence of the atmosphere by a protective blanket of ground charcoal.

CHAPTER XXI

SELECTIVE CASE HARDENING

The protection of certain portions of articles to be carburized against carburization, or selective case hardening, is a fairly important phase of this art. Sections to be left soft are coated with a mixture of 25% sodium silicate or water glass and 75% whiting, or are copper plated to prevent carbon penetration.

The latter method is the most trustworthy, and but a few thousandths of an inch of good dense copper plate is required to resist penetration of carbon with the use of a satisfactory carburizing material made for the purpose. Carburizing materials with a high content of energizer, especially those which are fusible at high temperatures, are destructive to copper plate.

It is our experience that Houghton's Hydro Carbonated Bone-Black, which is charred raw bone, charged with an oil rich in free carbon, is the best carburizing medium for copper plated work.

Hydro Carbonated Bone-Black can be used satisfactorily with a thinner coating of copper plating than any other carburizing material on the market; in fact, the use of materials containing energizers for this class of work is not fool-proof.

COPPER PLATING

The steel to be copper plated must be cleansed free of all oil, grease and rust, inasmuch as the Japan will not adhere to an unclean surface. The areas to be carburized are then Japanned with a high quality Japan.

The work is then baked for two hours at 320° to 340° F., and then placed on the racks and hangers in the

plating machine, which is set in motion, carrying the work through the baths in the following sequence:

1. The cleaning solution at a temperature of 180° F.
2. A solution of 1 part muriatic acid and 1 part water.
3. Cold running water.
4. A 1% solution of cold water and sodium cyanide.
5. Cold running water.
6. Plating bath for approximately fifteen minutes.
7. Cold running water.
8. Boiling water for drying.

The plating is then inspected and ready for the carburizing operation.

The copper is deposited electrolytically upon the unjapanned areas by means of a direct current generator operated at 6 volts and 10 amperes to each square foot of the work in solution.

A plating bath of the following composition produces satisfactory results:

Water	100 gals.
Sodium cyanide	22 lbs.
Copper cyanide	20 lbs. 12 oz.
Soda ash	12 lbs.
Sodium thio-sulphate	3 lbs. 2 oz.

The salts are dissolved directly in the water in the mixing tank.

Pure copper anodes are hung in the solution from the anode rods providing the copper plating.

Sodium cyanide is present for two reasons: first, to hold the copper of the bath in solution, and second, to produce an even non-porous plating. It prevents a porous plate due to the fact that it produces a finer crystalline grain size, making the plate more compact and less porous, hence better enabled to withstand penetration of the carburizing gases. The porosity or crystalline size increase with a decrease in the sodium cyanide content. The NaCN, dissolved in the bath, is continually decomposing

into its constituents Na and CN, hence, must be continually added to in the bath. This need may be judged in two ways: first, by continuous visual inspection of the work, and second, by chemical analysis. An experienced plater is able to judge the porosity of the plate by its appearance, and as a result is able to regulate the cyanide content which should bear the relation with copper of about 2 Cu to 1 CN.

The sodium carbonate (soda ash) content remains unchanged and requires no addition. The purpose of this salt is to act as a conductor for the current.

The sodium thio-sulphate has no action on the plating except to produce a cleaner, brighter plate.

The bath once started requires no further adjustment except to replenish the sodium cyanide as required, and to hold the copper up to 120 anodes or about 1200 pounds.

In time, however, the bath becomes "dead"; that is, there is no action when work is introduced for plating. At such a time a portion must be thrown away and the bath replenished with new material.

The amperage regulates itself according to the load introduced.

PRECAUTIONS TO BE OBSERVED

Surface to be plated must be absolutely clean before entering the plating bath.

The work must not be handled after it enters the potash tank, as this will leave thin spots on the plated work.

The Japan must be baked hard and contain no imperfections.

Solutions should be skimmed twice a day before starting the machine.

Thorough mechanical inspection of the plating machine should be made while in operation to keep the baths clean.

A continual inspection of brush contacts on the bus bar over the bath is necessary.

Keep all metallic objects off the bus bars as these cause short circuits.

Place work firmly in the hangers.

Always see that all pieces pass beneath the surface of all baths.

Load each side of the hangers evenly or they will tip, exposing the work.

The machine is not dangerous electrically, as it carries only 6 volts. The only danger is a slight burning due to high amperage.

SELECTIVE HARDENING OF CARBURIZED PARTS AND MACHINING AFTER HARDENING

Occasionally a part is so designed that a portion of it is threaded and it is essential the threads be true and soft; the remainder of the part requiring hardness for wear. As a rule when a threaded part is carburized and hardened, it is warped and thrown out of centre with the ground surface of the rest of the piece.

To overcome this, the following method has been successful, although more time is required.

The part is machined for carburizing, leaving about ¼ inch of stock on section to be threaded. After carburizing and cooling in the pot, this ¼ inch is turned to within 1/64 inch of size. The part is then hardened by double treating, after which the hardened surfaces are ground. The end or section to be threaded is then turned to size (the remaining 1/64 inch), true to the ground surfaces, and then threaded. When this ¼ inch is turned off the carburized zone is entirely machined off, leaving the soft core, and with careful selection of steel and control of treatment, there is no difficulty in the final machining operations.

Summarizing the operations they are as follows:

First—Machine for carburizing, leaving ¼ inch of stock on section to be threaded.

Second—Carburize at 899° C. (1650° F.) for depth of case desired, and cool in pot.

Third—Turn off all but 1/64 inch of the ¼ inch stock left on section to be threaded.

Fourth—Heat to 815° to 871° C. (1550°-1600° F.), quench in water or oil. Reheat to 760° to 780° C. (1400°-1440° F.), quench in water or oil.

CHAPTER XXII

GENERAL DISCUSSION OF HARDENING AND CARBURIZING TROUBLES

In spite of the most careful operation of a hardening or case hardening plant, troubles will arise which are often perplexing and seem to offer no solution, coming and disappearing at irregular intervals for no apparent reason.

Hardened work is subject to the following faults: soft spots, excessive warpage, cracking and unexplainable variations in fracture. The same faults are found in carburized work after hardening and the discussion which follows can be applied generally to high as well as low carbon carburized steel.

SOFT SPOTS

Soft spots on hardened work constitute more of the troubles of the average hardener than anything else.

If work after being quenched is soft in spots to the file, the hardening operation should be carefully checked. If the quench is such that steam forms on the surface, or part of the surface, and is not removed by the quenching action, soft spots will be found where steam has formed. The formation of steam is caused by rough machining which prevents the quenching water from coming in close contact with the surface of the work; by lack of circulation of the quench; or by pockets in the work which prevent the steam formed from escaping and the quenching water from circulating.

It should be remembered that the cooling of the work is obtained by the absorption of heat from the work by the quenching water and in order that the transfer of heat may take place at maximum speed, the water must

be in direct contact with the hot metal. This is impossible if the water does not move away from the hot surface before it reaches a temperature sufficient to form steam. This necessitates circulation and while natural circulation due to difference of temperature of the bath is sufficient for certain classes of work, such as very thin pieces, the average piece requires positive circulation in order that the water may leave the hot surface before steam is formed.

Rough machining, scale and pockets all tend to permit steam to form, and where ordinary circulation fails it may be necessary to resort to high pressure sprays. This is generally the case when hardening dies are used for cold drawing, or dies having deep impressions. Spray quenching when properly applied is one of the best assurances of hard work. It is too severe for many tools, but can nearly always be used with success on case hardened work.

Soft spots due to under heating are rare and can be easily checked by fracture, and eliminated.

Soft spots due to oxidation or local decarburization are occasionally found and can be detected by a careful anneal in charcoal and miscroscopic inspection.

In spite of the most careful observance of the above rules there are times when soft spots will occur, and generally to such an extent that department operation is ultimately upset and it is necessary to call in outside help. This is especially true in the case of carburized work, and as soon as such an epidemic of soft work occurs it is customary to pass the trouble on to the carburizing department and to that mysterious agent known as the "compound."

By carefully checking the carburized work, or better still, by very carefully annealing hardened work which is soft, it will be found that the carbon concentration is apparently good and there appears no reason why it should not harden.

Carburizing compound that is clean; that is, free from clay or sand, and has been purchased from an old established supplier, will, without doubt, give good results at all times and cannot affect the carburization to the extent that soft spots occur.

In fact, the cause of case carburized work which gives trouble due to soft spots in spite of the most careful hardening is hard to trace to the carburizing, and it has been definitely shown by the metallurgical department of the Timken Roller Bearing Company that the major cause of soft spots or soft work is the presence of dissolved oxides in the steel.

If steel is poorly deoxidized from the melting furnace, the martensite becomes very unstable and it is difficult to retain it, even with the most rapid cooling.

It can be readily seen that poor steel is thus the cause of most soft spots, since increased instability of the martensite requires increased speed of quenching, which is a hard condition to meet in practical operation.

As pointed out in Chapter XVIII, it is a simple matter to check the quality of the steel by carburizing and cooling slowly and then examining with a microscope, using a magnification of from 100 to 200 diameters. The cementite network and large grains of the hypereutectoid zone is evidence of good steel; the small heavy cementite fragments with small grains is characteristic of poorly made steel.

This test is easily made and should be carefully studied by every case hardener so that steel which will give trouble can be prevented from reaching the furnace.

Soft spots due to other conditions than those set forth above are very rare and of little consequence. It is important that the carburizing compound does not contain salts which are so combined in the compound as to form

"glass" on the work which in turn causes soft spots after quenching.

EXCESSIVE WARPAGE

Warped work after hardening may be due to either uneven quenching or uneven heating, and if case hardened, from improper packing.

If work is quenched so that one part cools more quickly than another, then the first part quenched will distort and cause the soft or unquenched side to follow accordingly. No definite rules may be given in regard to uniform quenching. Pieces having an uneven section should be quenched, immersing the heavy section first. They should, of course, be quenched so that the major axis of the piece is vertical. This is not so important with an oil quench, because when the cooling is slower the change in volume is relatively slow.

On pieces of uniform section, often occurring in large quantities, it pays to design a quenching fixture which will not only give a uniform quench, but also hold the piece in the shape desired as the quench is applied.

Uneven heating as a cause of warpage is unusual and easily detected by an experienced operator.

Improper packing in the carburizing pot may cause distortion after hardening if they are packed too tight, as the ordinary expansion due to the heat causes them to wedge or buckle.

HARDENING CRACKS

Cracks after hardening are caused by difference in expansion or contraction of the different parts of the work which set up tremendous strains unless relieved.

The formation of the hard structure desired (martensite), is accompanied by an increase in volume.

The first part to strike the water of the quench is chilled immediately and fixed in size with the formation of martensite, then from this fixed outside layer martensite is formed towards the center with increased volume.

After a short distance, usually not over one-thirty-second of an inch the cooling becomes slower with the formation of troostite and little if any volume change. takes place. Since the outside shell is fixed the volume change between it and troostite causes a tremendous pressure on the surface zone and has a tendency to burst the outside layer of martensite. This tendency is made greater by increasing the outside zone such as occurs when a heavy piece has a relatively light flange. The flange is fixed almost immediately, but the metal in the main body increases later and the expansion of the metal at the bottom of the flange thus causes a great pressure, enough often to cause the flange to fly to pieces.

Hardening cracks due to sudden change in section can be reduced by proper design, the use of large fillets, etc., and can be practically eliminated by using oil or warm water as a medium.

The result is not exactly as desired, metallurgically, but oftentimes gives a good product.

If water is necessary, holes should be clayed up, and the work should only remain in the water until it is below the drawing range or about 300° F. It should then be immediately transferred to the drawing furnaces and drawn at from 300° F. to 350° F.

Work which persists in cracking in spite of the greatest care when quenched in water should be quenched in oil or warm water, or, if necessary, be made from suitable alloy steel.

On case hardened work, cracking may be due to excessive carbon concentration or too low a quenching temperature.

Excessive carbon content tends to cause cracking, if the quench is severe, the work heavy with relatively thin flanges, etc., and heating not thorough. This combination causes, especially on thin flanges and heavy sections, deep martensite, with large crystals and undissolved plates of cementite. The deep martensite causes great strains; the

weakening of the structure by the plates of cementite reduces the ability to withstand such a strain.

Engineers in designing tools and fixtures should cooperate with the metallurgist to avoid losses due to hardening cracks, etc., which are often blamed on poor handling, but which as often can be traced to the engineering department.

VARIABLE FRACTURE

If hardened pieces are broken after hardening and an examination is made of the fracture, much can be learned of the previous history of the piece. Coarse crystals indicate too high a temperature, or too long a period at the hardening temperature. Coarse structure at the center of a high carbon piece and a fine grained structure near the surface, indicates improper annealing together with too low a hardening temperature, or too short a time at the proper temperature.

A fine grained fracture of an undulating appearance indicates proper annealing and hardening. If the piece fractured has been case hardened, a fine grained case and a coarsely crystalline core indicates a single treatment at the proper temperature for the case.

A coarsely crystalline case with a core of small grain size or fibrous appearance indicates a single treatment at too high a temperature for the case.

A finely drawn up center with a finely drawn up case indicates a double treatment with proper temperature used for both treatments.

If both case and core are coarsely crystalline with little difference in appearance between them it indicates that the piece was given a single treatment at too low a temperature for the case.

A finely drawn up case with coarse crystals at the edge and corners indicates a single treatment at the proper temperature for the normal case, but with heavy crystals of high carbon steel at the surface, showing that the piece

had been carburized at too high a temperature. A good quench is indicated by a uniformly drawn up case, with a distinct difference between case and core.

A wavy or irregular case indicates uncertain quenching, or unstable martensite caused by poorly made steel.

A very finely drawn up case apparently independent of ordinary fluctuations in temperature, together with soft spots, indicates poorly made steel, which condition warrants further checking.

CHAPTER XXIII

TESTING

In order to determine the physical characteristics of metals a system of tests is necessary, and tests are made by the metallurgist to verify the results of his operations, and by the engineer to ascertain if his material fulfills the specifications.

The character of metals can be affected by the following factors: the chemical composition, the methods employed in smelting or converting, and the mechanical and heat treatment to which the metal has been subjected. It is difficult to say which of these is more important, and no one factor can be disregarded.

The tests employed to check up or to ascertain these factors are chemical analysis, microscopic examination and various mechanical proofs. All these tests may be as important to the engineer as to the metallurgist because, although the mechanical tests alone may assure him that the material to be employed for a structure or machine has strength enough or possesses satisfactory wearing qualities, there are frequently cases where heat treatments must be practiced at certain stages of manufacture, and consequently the chemical composition and even the microscopic structure becomes of vital interest to him.

It is obvious that the most satisfactory test is to put the piece to the service for which it is intended, and observe its behavior. Such service tests, of course, are impractical in nearly every case, and reliance must be put on tests of samples only. This immediately opens the question as to what are the proper samples to use and how far the results of tests on small and isolated samples can be taken as representing the mass of material actually put in service. The confusion and error resulting from

differing and often misleading tests has shown the necessity of standardization of testing methods, and at present there is a very general uniformity in testing, owing very largely to the good work of such institutions as the American Society for Testing Materials, the American Society of Mechanical Engineers, and other domestic and foreign scientific and technical organizations.

The composition is tested by chemical analysis, which is simply a sequence of chemical reactions by which the presence of individual elements is indicated by the behavior of the material when treated with various reagents. By a process of careful weighing, not only the element present, but the actual amount of it, can be found, and the true percentage composition determined.

For example, in the estimation of carbon, the sample of steel is finely divided and heated in a current of pure oxygen gas. All the carbon in the iron is thus converted into carbon dioxide gas. This carbon dioxide gas is absorbed in a solution of lime and caustic soda, forming calcium and sodium carbonates. The solution will thus be increased by the exact weight of the carbon dioxide produced and absorbed, and by careful weighing before and after the operation the amount of carbon dioxide can be accurately found by their differentials. The amount of carbon, therefore, which was in the sample of steel is thus ascertained. The amount of phosphorus, sulphur and all other elements which may be present are ascertained by various chemical reactions, and standard methods for carrying out such analyses have been adopted. The details of chemical analyses cannot be described here, but are dealt with in works on elementary chemistry.

Chemical analyses for metallurgical purposes do not usually extend to very great refinements. It is usually sufficient to determine only the proportion of certain definite elements. For example, for an analysis of steel, in practically every case it is only necessary to know the proportion of carbon, silicon, phosphorus, sulphur, manganese, and perhaps one or more alloying elements, although

chemically considered there may be many other elements present, though possibly only in very small quantities.

Tests by chemical analyses are needed in the first place when dealing with the ore, and from the knowledge thus obtained the flux, fuel and treatment in reduction or smelting are regulated. In operating a blast furnace analyses are made at every cast, and in processes of steel conversion in the open hearth one or more preliminary tests and later a ladle analysis are made. In the marketing of ores, the chemical analysis is often the base on which the price is fixed.

The knowledge of the chemical composition as determined by analysis is also necessary when heat treatments are to be prescribed. For this purpose it is essential to know the carbon content as well as the alloying elements.

Specifications often define the chemical compositions as well as the physical properties desired, and in this connection it may be pointed out that the specification of the amount of certain elements within very close limits is unnecessary and results only in increasing the difficulty of production. For instance, an element may be specified as required in an amount between 25% and 27%, when the same result can be obtained with amounts above or below these limits. It is more satisfactory in such a case to specify 20% to 30%. In general it would be of great benefit if engineers adhered to specifications drawn up and sanctioned by the various recognized scientific and technical societies, such as the American Society for Testing Materials or the Society of Automotive Engineers, rather than formulated specifications of their own.

Tests for structure, in the same way, are useful in connection with heat treatments and mechanical treatment. In such tests, or investigations, the minute structure of the metal can only be examined through the microscope with the use of prepared specimens. The usual method is to photograph a representative section through the microscope, producing a micrograph which can be examined carefully and serve as a record. Microscopic tests are

slow and expensive, and therefore can be only used in special cases.

The tests most commonly made are in relation to the strength of materials, and on these results judgment can be made as to the power the material possesses of resisting stresses of all kinds. Stresses are produced by the application of force to the material and can be divided into two main classes: static, or steady loads, and dynamic, or sudden loads, although this classification is properly only for convenience, because in reality the difference is relative. There are, in fact, only two fundamental ways in which force can be applied to material. It can only be pulled or pushed, that is, put under tensile or compressive stress; but these two ways may be so combined, and may so alternate and change in direction and intensity, that stresses are produced which are classed as torsional, bending, shearing, impact and fatigue. No material is known which is absolutely rigid, that is to say, every substance known, when a change in the very slightest degree is made in the force or forces acting on it, will alter in shape. It may be, of course, only to an imperceptible extent, but the alteration is there, nevertheless. It is, therefore, necessary to consider the relative degree of the characteristics of substances, in connection with the mobility of the particles of which they are made up, and their character of plasticity. When a material is in the gaseous state it has little or no power of resisting change of shape; when in the liquid condition its power of resistance is very little different; and when in the solid state it is very much greater, but we do not know that any material can ever become absolutely rigid. Little is known about the ultimate constitution of matter, and the explanations of why some substances are soft, some hard, and others tough or brittle, is still largely only founded on speculation. The practical metallurgist and engineer cannot spend time in inquiring into matters much beyond immediate needs, and therefore specifications and designs

must for the present be based upon proven experimental facts.

The common tests which will give the information usually desired are the tension test, which gives the properties of the material when under a steady load, and indicating the elastic limit, the ultimate strength and the percentage of elongation and contraction of area; the hardness test, which gives the resistance to penetration and also resistance to wear; and the impact test, which gives the resistance to sudden shocks.

In the tension test a sample of steel, or whatever material is to be tested, is shaped into a test bar, which is so made that it can readily be attached to the testing machine, and also has a weakest part where the testing stresses will be definitely evidenced and where observation and measurements can conveniently be made. Tensile testing machines are simply appliances by which a steady

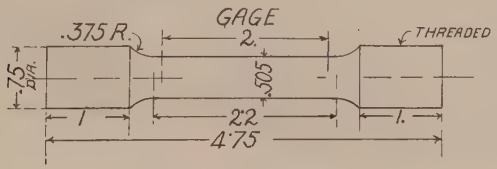


FIG. 90
TENSILE TEST SPECIMEN

pull can be exerted on the test piece. The amount of the pull in pounds (or kilograms) can be varied, and indicated at every instant of time. Tensile testing machines may be operated by a system of levers acted on by some prime mover such as an electric motor, the pull exerted being indicated in the same manner as in weighing scales; or operated by hydraulic power, the pull exerted again being indicated by weights which can be balanced through a system of levers. The test bar is placed in the machine, the section of the bar where the stress will be concentrated

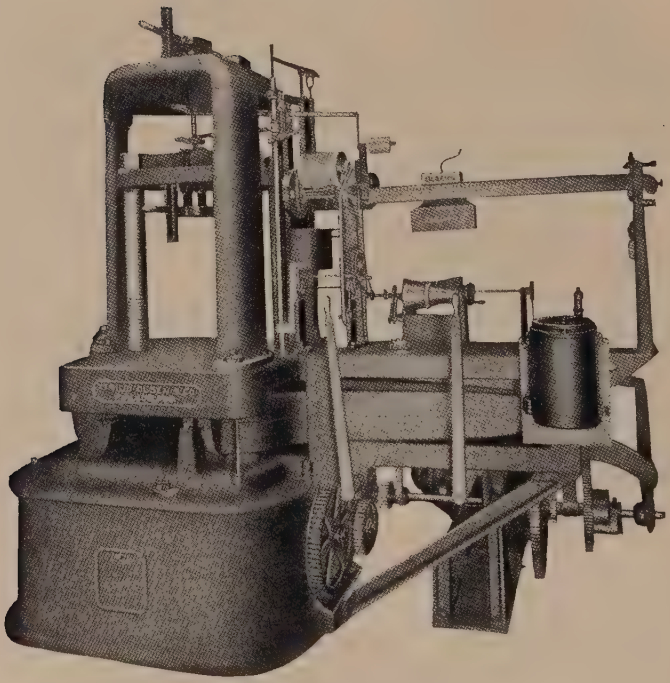


FIG. 91
TENSILE TESTING MACHINE

carefully measured, and an arbitrary length marked off on the bar where the stress is concentrated. An increasing pull is then exerted on the bar, which will begin to stretch and finally break.

During the pulling there are certain definite phases to be noted, but these phases are not present in all materials. An example of what occurs with steel will give an idea of these phases. If now known loads or pulls are applied to the bar, each load or pull being greater than

the previous load, and if the distance between the two marks on the test piece is carefully measured at the time each load is applied; also if the load or pull is removed after each application and the distance between the marks carefully measured again, when there is no pull in action, it will be found that, up to a certain load, the test bar which stretched under the action of the load returns to its original length when the load is removed, but on applying an increased load, and removing it, it will be found that the bar does not return to its original length, it has in fact been permanently stretched, or as usually described, it has received a permanent deformation or set. The test bar, therèfore, is elastic when acted on by loads less than the load or pull which can be determined in this way.

The load or pull above which the test piece cannot be pulled without being permanently elongated is called the elastic limit, and can be considered as one of the phases of the tensile test. Again, if in the same way extensions and loads are noted in regularly increasing loads, beginning with no load, it will be found that up to a certain point the extensions are directly proportional to the loads, but beyond this the extensions and loads are no longer proportional. This point is called the proportional limit. If pulling is continued with increasing loads beyond these points, the test piece stretches more rapidly until it finally breaks, sometimes necking down before breaking, so that the section where the break takes place is much less than the original section of the test piece. The highest load that is recorded before breaking is called the ultimate or tensile strength.

The two broken pieces of the test bar are then fitted together and the final distance between the two original marks is measured, and the area of the section where the rupture took place is also measured. Knowing all these measurements and loads, the load in pounds per square inch of section (or kilograms per square centimeter) at

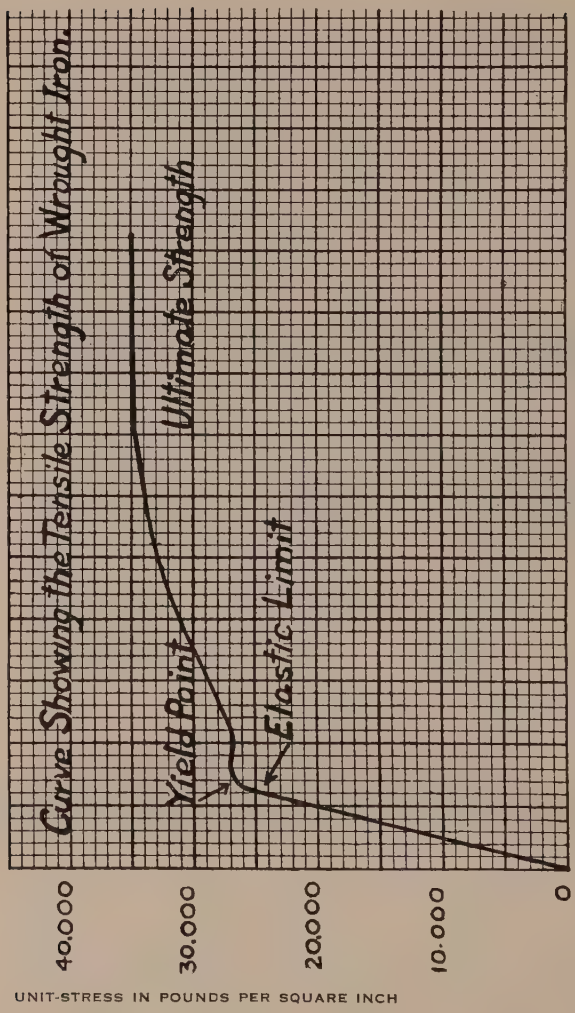


FIG. 92

STRESS-STRAIN DIAGRAM OF WROUGHT IRON

the elastic limit, the proportional limit and the ultimate strength can be calculated, the per cent increase of distance between the marks, and the per cent decrease in area of the cross section can also be calculated. These phenomena have been studied very thoroughly by innumerable investigators, and certain laws have been deduced from them. As far back as 1676, Thomas Hooke wrote on "the true theory of elasticity," that "as the stretching is, so is the strength." The general attitude towards science in those days may be imagined when it is pointed out that this Thomas Hooke, although English was his native language, not only wrote the above in Latin, as "ut tensio, sic vis," but also further concealed the sentence in a childish anagram, thus, "c e i i i n o s s s t t u v !" The modern way of expressing this is—"Inside the elastic limit the stress is directly proportional to the deformation which accompanies it." From this law an important ratio known as Young's Modulus, or the modulus of elasticity has been deduced, this is the ratio between the force which causes the deformation and the deformation itself, and is a constant for each material considered. The modulus of elasticity of steel is about 30,000,000, which means in plain language that it would theoretically take a pull of 30,000,000 pounds to stretch a piece of steel one inch long and one inch in sectional area to a length of two inches; *i. e.,* providing it could be stretched so far without exceeding the elastic limit. Another useful ratio has been observed, which is called Poisson's Ratio. When a body is acted on by an external force in one direction, it may be tensile or compressive, stresses are set up in the material of a contrary nature and at right angles to the original force. This so-called Poisson's Ratio is different in different materials, ranging from about ¼ to ⅓, and in the case of steel, Poisson's Ratio may be indicated by saying that if a piece of steel is elongated one inch, its sectional area will contract about ⅓ of an inch.

The accurate determination of Poisson's Ratio is a difficult matter. In the common practice of testing metals,

the elastic limit, the tensile strength and the percentage elongation and contraction of area are generally recorded and a note is made of the appearance of the fracture—if fibrous, silky or granular and crystalline. The properties of the material from which the sample has been taken and from which the test bar has been made can, therefore, be judged, and the engineer can proceed with his design and fix his factors of safety.

Testing in a similar manner can, of course, be made by using compressive loads, but it has been found that in the case of steel, the elastic limit in compressive stress is about the same as in tensile stress, and compression tests are more commonly made on material other than steel.

The tensile test indicates the strength and ductility of a material when subjected to steady and slowly changing loads, but it does not show how the material will act when subjected to very quickly applied loads, or shocks. Many steels and other materials will show excellent results in the tensile test, but under shocks will appear brittle. The impact test is the test for determining the resistance to shock, or for ascertaining the degree of brittleness of a material. Up to the present time impact tests have not been developed to a state where satisfactory absolute measurements can be made, and so are relative only. The impact test is made by comparing the amount of work performed in fracturing similar test bars by a mass of a known weight moving at a known speed when striking the test bar.

There are several types of impact machines, working according to the following principles or actions: as a blow struck by a weight falling directly under the action of gravity; by a swinging pendulum weight also actuated by gravity, or by a revolving weight acting as a fly-wheel with stored energy. In all cases the method of determining the work actually performed by the weight in breaking the specimen is by finding the difference between the energy of the weight both just before and after impact and the rupture of the specimen, and thereby assuming that

this difference represents the energy needed in the fracturing of the specimen. There is much difference of opinion on this subject and the absolute value of results obtained is open to question. However, the test has been proved to be of great practical value, and in most cases the comparative rather than the absolute measurement is all that is required.

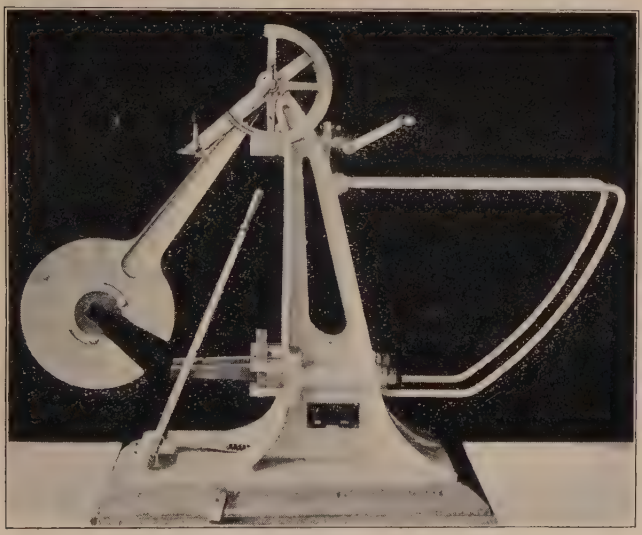


FIG. 93
IMPACT TESTING MACHINE, PENDULUM TYPE

Impact tests are of two kinds, one in which manufactured articles, such as axles, railroad tires, etc., are subjected to blows of known intensity from falling weights, also the number of blows the piece will bear without fracturing, and the deformation it suffers at one or more blows is taken as the measure of the test; and in the other a sample of the material only is taken, in the form of a definitely shaped test bar, then broken and the energy

required to cause the fracture measured (as above mentioned), and used as a comparative figure. The former type of test is used largely as a proof test in the manufacture of railroad material, the latter type is confined to testing laboratories.

Considering that impact tests are comparative, the type and dimensions of the test bar become of great import-

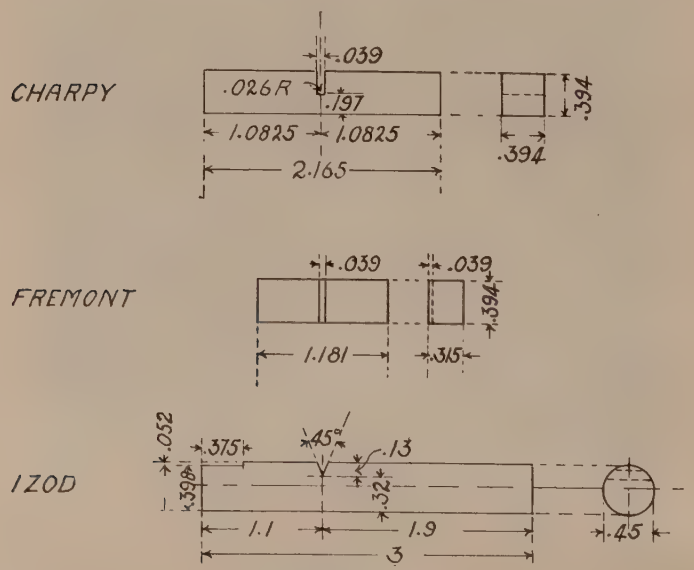


FIG. 94
IMPACT TEST SPECIMENS

ance. The test bar is notched in order to localize the stress and prevent an initial deformation of the material. The size and shape of this notch also becomes a matter of importance, because it has been found that the shape of the notch has influence on the result of the test. It is, therefore, generally agreed that a type of notch should

be chosen which can be easily duplicated with great exactness. There are three common types—a notch made in a "V" shape, having a fixed angle, and a fixed radius of rounding at the bottom of the "V"; a notch made by drilling a hole of fixed diameter through the test piece, and sawing a slit from the hole to the outside of the test piece; and a notch made by a saw-cut of fixed width and depth.

Impact tests are not very satisfactory in dealing with material having more than a certain degree of toughness, because the test bar does not actually break into two pieces but is bent, and the errors introduced by friction, etc., make the results quite unreliable.

The hardness test is again a comparative test. In this test the comparative resistance of a material to penetration is measured. The common hardness testing machine is the Brinell machine, in which a hard steel ball of carefully measured diameter is pressed into the material to be tested with a constant pressure. Accordingly as the material is either comparatively soft or hard, the impression made by the ball will be deeper or shallower. In practice the diameter of the impression is measured and recorded, and what is known as the Brinell number is calculated by a formula in which the load, the diameter of the ball and the diameter of the impression are factors.

$$\text{H, or hardness number} = \frac{2W}{D^{-}(D-\sqrt{-D^2—d^2})}$$

W being the load in kilograms, D the diameter of the ball in millimeters, and d the diameter of the impression in millimeters.

There is a close, but not absolute connection between the Brinell hardness number and the tensile strength of steels, and if the hardness number obtained by using a 10 mm. ball and a pressure of 3000 kgm. is multiplied by a coefficient, the product will give the approximate tensile strength.

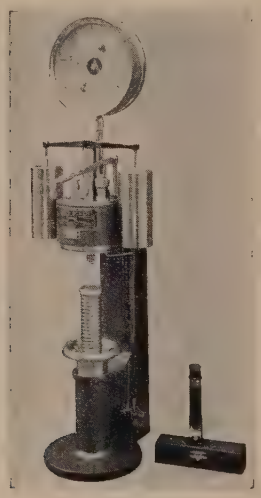


FIG. 95
BRINELL HARDNESS TESTING MACHINE

Comparative hardness is also tested by means of an instrument known as Shore's Scleroscope, in which a small hammer with a diamond-shaped point is allowed to fall down a glass tube free from a fixed height, and strike the surface of the material to be tested. The hammer after striking will rebound, and the height of rebound is the measure of the hardness. This method of comparison depends upon certain elastic qualities of material which are in close relation to so-called hardness.

A new type of testing machine has been introduced, known as the Rockwell testing machine for hardness.

This machine consists of an anvil and a plunger holding a diamond point. The diamond is forced into the surface of the steel under a constant pressure. The depth of the impression is read direct to 1/10,000 of an inch. The machine is calibrated to give a hardness reading in Brinell

numbers or in percentages. Electrolytic iron is taken as Zero per cent. and the diamond as 100 per cent. Hard. It can be used excellently as a comparative tester. Due to its small area of application, a great many shapes and surfaces may be tested accurately. Wire can be tested as small as .09 inch diameter. It requires no special preparation of the piece of steel to be tested, except in some cases a slight surface cleaning. The depth of indentation can be controlled so that no harm can be done to a finished surface.

The above-described tests are those most commonly used in industrial laboratory work and are practically the only tests commonly introduced into specifications for steel. There are, however, many other tests which are specified in special cases, and which are largely used in laboratory investigations of many classes of material. In the torsion test, the unit resistance to torsional stresses is obtained from a torsion machine, in which a test bar is held at one end and the other end twisted, means being provided to measure the load required to twist through angular distance and finally cause rupture by twisting. In the shear test, the unit resistance to shear given by a test bar is measured. This test can readily be carried out on an ordinary tensile testing machine by means of a simple fixture. In a similar way the resistance of a test bar to bending to a certain angle can be measured on an ordinary tensile testing machine.

There are also endurance and fatigue tests, repeated impact tests, alternating stress tests and others, most of which are useful not so much because of their absolute measurements as for their comparative measurements. For example, the accompanying illustration shows an endurance testing machine in which a specimen test bar is rapidly revolved. The bar is supported in the center and carries loads at either end, and thus each end is put under compressive and tensile stress at each revolution.

BRINELL HARDNESS NUMBERS AND ESTIMATED TENSILE STRENGTH FOR 3,000 KILOGRAM PRESSURE ON A 10 M/M BALL TESTING MACHINE.

Dia. of Impression in m/m	Hardness Numeral	Ultimate Pounds per Sq. In.	Dia. of Impression in m/m	Hardness Numeral	Ultimate Pounds per Sq. In.
2.00	946	465,100	4.00	228	112,600
2.05	898	442,100	4.05	223	109,700
2.10	857	421,600	4.10	217	106,900
2.15	817	402,000	4.15	212	104,200
2.20	782	383,700	4.20	207	101,600
2.25	744	366,600	4.25	202	99,100
2.30	713	350,600	4.30	196	96,700
2.35	683	335,700	4.35	192	94,400
2.40	652	321,600	4.40	187	92,200
2.45	627	308,400	4.45	183	90,000
2.50	600	295,900	4.50	179	87,900
2.55	578	284,300	4.55	174	85,800
2.60	555	273,300	4.60	170	83,900
2.65	532	262,900	4.65	166	82,000
2.70	512	253,100	4.70	163	80,100
2.75	495	243,800	4.75	159	78,300
2.80	477	235,000	4.80	156	76,600
2.85	460	226,600	4.85	153	74,900
2.90	444	218,700	4.90	149	73,300
2.95	430	211,200	4.95	146	71,700
3.00	418	204,100	5.00	143	70,200
3.05	402	197,300	5.05	140	68,700
3.10	387	190,800	5.10	137	67,200
3.15	375	184,600	5.15	134	65,800
3.20	364	178,800	5.20	131	64,500
3.25	351	173,200	5.25	128	63,100
3.30	340	167,800	5.30	126	61,800
3.35	332	162,700	5.35	124	60,600
3.40	321	157,800	5.40	121	59,400
3.45	311	153,100	5.45	118	58,200
3.50	302	148,600	5.50	116	57,000
3.55	293	144,300	5.55	114	55,900
3.60	286	140,200	5.60	112	52,800
3.65	277	136,200	5.65	109	53,700
3.70	269	132,400	5.70	107	52,700
3.75	262	128,800	5.75	105	51,700
3.80	255	125,300	5.80	103	50,700
3.85	248	121,900	5.85	101	49,700
3.90	241	118,700	5.90	99	48,800
3.95	235	115,500	5.95	97	47,900

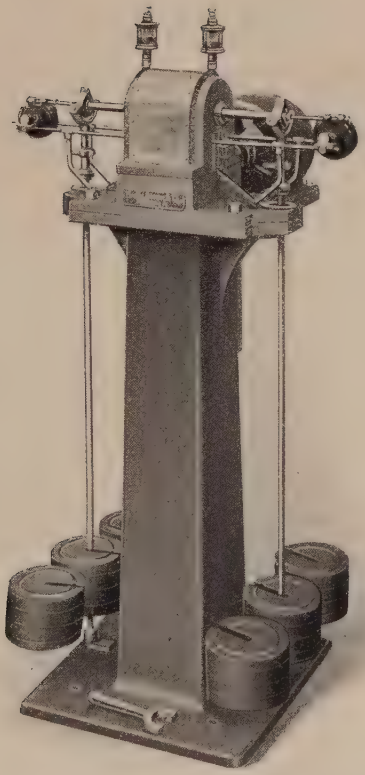


FIG. 96

ENDURANCE TESTING MACHINE

White Souther Type

CHAPTER XXIV

IRON AND STEEL SPECIFICATIONS

Definite applications of S. A. E. Steels are not covered hereinafter, as it will be readily appreciated that the selection of a proper steel for a given part must depend upon an intimate knowledge of a number of important factors, such as the availability and price of the material, the detailed design of the part and the severity of the service to be imposed, whether the part is to be forged or machined, machineability and the method of manufacture. Only after a careful consideration of these factors can the proper steels for the great variety of automotive parts be selected. By providing charts that show the conservative physical properties of the S. A. E. Steels, the designer is supplied with data that will in most cases enable him to prepare a list of satisfactory steels from the standpoint of physical properties, after which the final choice will depend upon such local conditions as machineability, heat-treating, delivery and price.

It is important to bear in mind when using the information in Section IX, General Heat-Treatments, that it is based on the tests and experience of steel manufacturers and consumers and is intended only as a guide in selecting the proper steels and their heat-treatment. Care has been taken to provide reliable data, but the steel users should supplement these data with suitable inspection tests and practices in order to be assured that each lot of material purchased will respond in a normal manner to the heat-treatments generally applied in their particular practices.

Variations in the effect of the usual forms of heat-treatment may be due to plant personnel, variations in the steel composition or manufacture and to changes in local

conditions, such as control and sensitiveness of heat-treating equipment. In order to overcome such variations, steel users should keep all heats of a given type and grade separate in the stock room and when routing them through the various shop operations, and preliminary tests should precede all production operations in order that the exact details of heat-treatment, particularly the normalizing, quenching and drawing temperatures, may be determined in advance for each lot of steel.

PART I—INTRODUCTION

S. A. E. STANDARD

The steel compositions included in this standard are considered adequate for practically all parts made of ferrous materials that are necessary for the production of automotive apparatus, and include grades that have been found commercially available and technically adequate for the service required of such parts. In cases where very special requirements or exceptional quality make it necessary, grades containing less phosphorous and sulphur and narrower ranges of carbon and manganese are available, but such steels should be obtained by special arrangement between the mill and the purchaser.

SPECIFICATION NUMBERS

A numeral index system is used for the specifications contained in this report, which makes it possible to use specification numerals on shop drawings and blueprints that are partially descriptive of the quality of material covered by such numbers. The first figure indicates the class to which the steel belongs: thus "1—" indicates a carbon steel; "2—" a nickel steel, and "3—" a nickel-chromium steel. In the case of the alloy steels, the second figure generally indicates the approximate percentage of the predominant alloying element. Usually the last two or three figures indicate the average carbon-content in "points," or hundredths of 1%. Thus "2340" indicates a nickel steel of approximately 3% nickel (3.25 to 3.75), and 0.40% carbon (0.35 to 0.45); and 71360 indicates a

tungsten steel of about 13% tungsten (12 to 15) and 0.60% carbon (0.50 to 0.70). The basic numerals for the various qualities of steels specified are:

Carbon Steels	1
Nickel Steels	2
Nickel-Chromium Steels	3
Molybdenum Steels	4[a]
Chromium Steels	5
Chromium-Vanadium Steels	6
Tungsten Steels	7
Silico-Manganese Steels	9

REGARDING SPECIFICATIONS AND NOTES ON HEAT-TREATMENTS AND PHYSICAL PROPERTIES

The Notes on heat-treatments and physical properties are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

S. A. E. Steels should be purchased on the basis of requirements as to chemical composition, and the specifications provided herein should be used in the purchase of the grades and types of steel covered by each. Requirements as to physical properties have been omitted for all steels except steel castings because the majority of steels for automotive purposes are either worked or given special heat-treatments by the purchaser.

PART II—SPECIFICATIONS FOR AUTOMOTIVE STEELS

S. A. E. STANDARD

Process.—The steel shall be made by the bessemer, open-hearth, crucible, electric, or any other process approved by the purchaser.

[a] This numeral has been agreed upon as the index to the Molybdenum group, but no specific compositions have as yet been approved.

Discard.—A sufficient discard shall be made from each ingot to secure freedom from injurious piping and undue segregation.

CHEMICAL PROPERTIES

The steel shall conform to the specified requirements as to chemical composition.

Ladle Analysis.—An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of the elements specified. This analysis shall be made from drillings taken at least ¼ inch beneath the surface of a test ingot obtained during the pouring of the melt, and in as sound metal as possible. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified.

Check Analysis.—Analyses may be made by the purchaser. The chemical composition thus determined shall conform to the requirements specified.

Drillings for analyses of bars, billets or other regular shapes shall be taken parallel to the axis, at any point midway between the center and the surface.

Drillings or cuttings for analyses or irregularly shaped pieces shall be taken from both the thickest and the thinnest sections. Surface drillings shall be discarded.

Wire, tubing, sheets, and rods less than 1¼ inch thick shall be sampled through or across the entire section.

FINISH

Defects.—The material shall be free from injurious defects and shall have a workmanlike finish.

INSPECTION AND REJECTION

Inspection.—The inspector representing the purchaser shall have free entry at all times to all parts of the manufacturer's works that concern the manufacture of the material ordered while work on the contract of the purchaser is being performed. The manufacturer shall afford the inspector free of cost all reasonable facilities to satisfy

him that the material is being furnished in accordance with these specifications. Tests and inspection at the place of manufacture shall be made prior to shipment.

The purchaser may make the tests to govern the acceptance or rejection of the material in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejections.—Unless otherwise specified, any rejection based on tests made by the purchaser in its own laboratory shall be reported within ten working days from the receipt of samples.

Material which shows injurious defects while being finished by the purchaser will be rejected, and the manufacturer shall be notified.

Rejection Tests.—Samples tested by the purchaser in its own laboratory that represent rejected material, shall be preserved for one month from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

PART III—CHEMICAL COMPOSITIONS

S. A. E. STANDARD CARBON STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.
1010	0.05–0.15	0.30–0.60	0.045	0.05
1015	0.10–0.20	0.30–0.60	0.045	0.05
1020	0.15–0.25	0.30–0.60	0.045	0.05
1025	0.20–0.30	0.50–0.80	0.045	0.05
1030	0.25–0.35	0.50–0.80	0.045	0.05
1035	0.30–0.40	0.50–0.80	0.045	0.05
1040	0.35–0.45	0.50–0.80	0.045	0.05
1045	0.40–0.50	0.50–0.80	0.045	0.05
1046	0.40–0.50	0.30–0.50	0.045	0.05
1050	0.45–0.55	0.50–0.80	0.045	0.05
1095	0.90–1.05	0.25–0.50	0.040	0.05

SCREW STOCKS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Range
1112	0.08–0.16	0.60–0.80	0.09–0.13	0.075–0.15
1120	0.15–0.25	0.60–0.90	Max. 0.06	0.075–0.15

STEEL CASTINGS

S. A. E. Steel No.	Carbon	Phosphorus, Max.	Sulphur, Max.
1235	As required by physical properties	0.05	0.05

NICKEL STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Nickel Range
2315	0.10–0.20	0.30–0.60	0.04	0.045	3.25–3.75
2320	0.15–0.25	0.50–0.80	0.04	0.045	3.25–3.75
2330	0.25–0.35	0.50–0.80	0.04	0.045	3.25–3.75
2335	0.30–0.40	0.50–0.80	0.04	0.045	3.25–3.75
2340	0.35–0.45	0.50–0.80	0.04	0.045	3.25–3.75
2345	0.40–0.50	0.50–0.80	0.04	0.045	3.25–3.75
2350	0.45–0.55	0.50–0.80	0.04	0.045	3.25–3.75
2512	Max. 0.17	0.30–0.60	0.04	0.045	4.50–5.25

CHROMIUM STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Chromium Range
5120	0.15–0.25	0.30–0.60	0.04	0.045	0.60–0.90
5140	0.35–0.45	0.50–0.80	0.04	0.045	0.80–1.10
5150	0.45–0.55	0.50–0.80	0.04	0.045	0.80–1.10
52100	0.95–1.10	0.20–0.50	0.03	0.030	1.20–1.50

NICKEL-CHROMIUM STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Nickel Range	Chromium Range
3115	0.10–0.20	0.30–0.60	0.04	0.040	1.00–1.50	0.45–0.75
3120	0.15–0.25	0.30–0.60	0.04	0.045	1.00–1.50	0.45–0.75
3125	0.20–0.30	0.50–0.80	0.04	0.045	1.00–1.50	0.45–0.75
3130	0.25–0.35	0.50–0.80	0.04	0.045	1.00–1.50	0.45–0.75
3135	0.30–0.40	0.50–0.80	0.04	0.045	1.00–1.50	0.45–0.75
3140	0.35–0.45	0.50–0.80	0.04	0.045	1.00–1.50	0.45–0.75
3215	0.10–0.20	0.30–0.60	0.04	0.040	1.50–2.00	0.90–1.25
3220	0.15–0.25	0.30–0.60	0.04	0.040	1.50–2.00	0.90–1.25
3230	0.25–0.35	0.30–0.60	0.04	0.040	1.50–2.00	0.90–1.25
3240	0.35–0.45	0.30–0.60	0.04	0.040	1.50–2.00	0.90–1.25
3245	0.40–0.50	0.30–0.60	0.04	0.040	1.50–2.00	0.90–1.25
3250	0.45–0.55	0.30–0.60	0.04	0.040	1.50–2.00	0.90–1.25
3312	Max. 0.17	0.30–0.60	0.04	0.040	3.25–3.75	1.25–1.75
3325	0.20–0.30	0.30–0.60	0.04	0.040	3.25–3.75	1.25–1.75
3335	0.30–0.40	0.30–0.60	0.04	0.040	3.25–3.75	1.25–1.75
3340	0.35–0.45	0.30–0.60	0.04	0.040	3.25–3.75	1.25–1.75
3415	0.10–0.20	0.45–0.75	0.04	0.040	2.75–3.25	0.60–0.95
3435	0.30–0.40	0.45–0.75	0.04	0.040	2.75–3.25	0.60–0.95
3450	0.45–0.55	0.45–0.75	0.04	0.040	2.75–3.25	0.60–0.95

CHROMIUM-VANADIUM STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Chromium Range	Vanadium	
						Min.	Desired
6120	0.15–0.25	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6125	0.20–0.30	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6130	0.25–0.35	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6135	0.30–0.40	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6140	0.35–0.45	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6145	0.40–0.50	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6150	0.45–0.55	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6195	0.90–1.05	0.20–0.45	0.03	0.03	0.80–1.10	0.15	0.18

TUNGSTEN STEELS

S. A. E. Steel No.	Carbon Range	Manganese, Max.	Phosphorus, Max.	Sulphur, Max.	Chromium Range	Tungsten Range
71360	0.50–0.70	0.30	0.035	0.035	3.00–4.00	12.00–15.00
71660	0.50–0.70	0.30	0.035	0.035	3.00–4.00	15.00–18.00
7260	0.50–0.70	0.30	0.035	0.035	0.50–1.00	1.50– 2.00

SILICO-MANGANESE STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Silicon Range
9250	0.45–0.55	0.60–0.90	0.045	0.045	1.80–2.20
9260	0.55–0.65	0.60–0.90	0.045	0.045	1.80–2.20

PART IV—STEEL CASTINGS[1]

Specification 1235

S. A. E. STANDARD

Process.—The steel may be made by any process approved by the purchaser. Three grades are recognized: hard, medium and soft.

Cooling.—All castings shall be allowed to become cold. They shall then be reheated uniformly to the proper temperature to refine the grain and allowed to cool uniformly and slowly.

CHEMICAL COMPOSITION AND TESTS

Analysis.—The castings supplied shall conform to the following chemical requirements in percentage on check analysis:

Carbon	As Required for Physical Properties
Phosphorus, not to exceed.....	0.05
Sulphur, not to exceed.....	0.05

[1] This specification is substantially the same as Specification No. A27-14 of the American Society for Testing Materials.

Drillings.—Drillings for analysis shall be so taken as to represent the average composition of the casting.

PHYSICAL PROPERTIES AND TESTS

Tensile Test.—The tensile properties of finished castings shall conform to the following minimum requirements:

	Hard	Medium	Soft
Tensile-Strength, lb. per sq. in..	80,000	70,000	60,000
Yield-Point, lb. per sq. in.....	36,000	31,500	27,000
Reduction of Area, per cent....	20.0	25.0	30.0
Elongation in 2 In., per cent....	15.0	18.0	22.0

Bend Test.—The test-specimens for soft castings shall bend cold through 120°, and for medium castings through 90°, around a 1-in. diameter pin without cracking on the outside. Hard castings shall not be subject to bend-test requirements.

Test to Destruction.—For small or unimportant castings, a test to destruction on three castings from a lot may be substituted for the tension and bend tests. This test shall show the material to be ductile, free from injurious defects and suitable for the purpose intended. A lot shall consist of all castings from one melt in the same annealing charge. In case test-bars are cast separately, they shall be annealed with the lot they represent. The method of casting such test-bars, or casting test-bars attached to castings, shall be agreed upon by purchaser and manufacturer.

Tension Test.—Tension test-specimens shall be machined to conform to the S. A. E. Standard Round Tension Test-Specimen, Fig. 97, and S. A. E. Standard Flat Tension Test-Specimen, Fig. 98. Bend test-specimens shall be machined to 1 x ½-in. section, with corners rounded to a radius of not over 1/16 in.

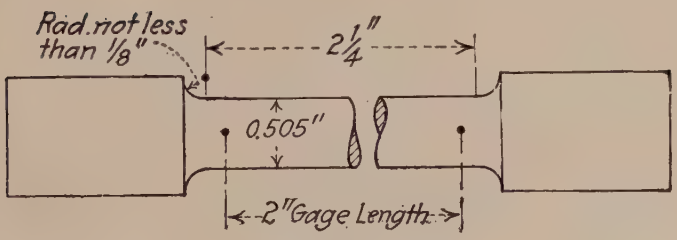


FIG. 97
ROUND TENSION TEST-SPECIMEN

Number of Tests.—One tension and one bend test shall be made from each annealing charge. If more than one melt is represented in an annealing charge, one tension and one bend test shall be made from each melt.

Defective Test-Specimens.—If any test-specimen shows defective machining or develops flaws it may be discarded, in which case another test-specimen may be selected by the manufacturer and the purchaser.

Retests.—A retest shall be allowed if the percentage of elongation is less than that specified or if any part of the fracture is more than ¾ in. from the center of the gage length as indicated by scribe scratches marked on the test-specimen before testing.

WORKMANSHIP AND FINISH

Finished Castings.—The finished castings shall conform substantially to the sizes and shapes of the patterns, shall be made in a workmanlike manner and be free from injurious defects.

MARKING OF CASTINGS

Marking Castings.—The manufacturer's identification mark and the pattern numbers assigned by the purchasers shall be cast on all castings of sufficient size, in such positions that they will not interfere with the service of the castings.

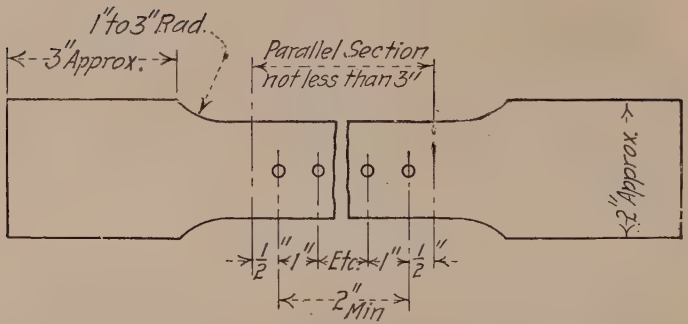


FIG. 98

FLAT TENSION TEST-SPECIMEN

INSPECTION AND REJECTION

Defective Castings.—Minor defects that do not impair the strength of the castings may, with the approval of the purchaser, be welded by an approved process. The defects shall first be cleaned out to solid metal and after welding the casting shall be annealed.

Hidden Defects.—Castings offered for inspection shall not be painted or covered with any substance that will hide defects, nor rusted to such an extent as to hide defects.

PART V—MALLEABLE IRON CASTINGS[1]

S. A. E. STANDARD

Material.—These specifications cover malleable iron castings for general automotive purposes.

Process.—The castings shall be produced by either the air-furnace, open-hearth, or electric-furnace process.

PHYSICAL PROPERTIES AND TESTS

Tensile Tests.—The tensile properties of the test-specimens specified shall conform to the following minimum requirements:

[1] This specification practically conforms to Specification No. A47-19 of the American Society for Testing Materials.

Tensile Strength, lb. per sq. in.....	45,000
Elongation in 2 In., per cent.....	7.5

Special Tests.—All castings, if of sufficient size, shall have cast thereon test-lugs of a size proportional to the thickness of the casting, but not exceeding 5/8 by 3/4 in. in cross-section. On castings which are 24 in. or over in length, a test-lug shall be cast near each end. These test-lugs shall be attached to the casting at such a point that they will not interfere with the assembling of the castings, and may be broken off by the inspector.

If the purchaser or his representative so desires, a casting may be tested to destruction. Such a casting shall show good, tough malleable iron.

Tension Test-Specimens.[1]—Tension test-specimens shall be of the form and dimensions shown in Fig. 99. Specimens whose mean diameter at the smallest section is less than 19/32 in. will not be accepted for test.

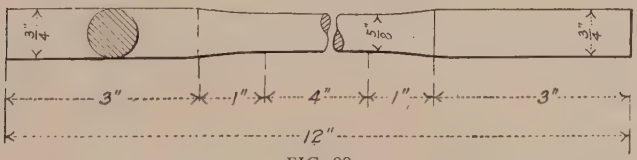


FIG. 99

MALLEABLE IRON TENSION TEST-SPECIMEN

A set of three tension test-specimens shall be cast from each melt, without chills, using heavy risers of sufficient height to secure sound bars. The specimens shall be suitably marked for identification with the melt. Each set of specimens so cast shall be placed in some one oven containing castings to be annealed.

Number of Tests.—After annealing, three tension test-specimens shall be selected by the inspector as representing the castings in the oven from which these specimens are taken.

[1] Tension test-specimens are not machined.

If the first specimen conforms to the specified requirements, or if, in the event of failure of the first specimen, the second and third specimens conform to the requirements, the castings in that oven shall be accepted, except that any casting may be rejected if its test-lug shows that it has not been properly annealed. If either the second or third specimen fails to conform to the requirements, the entire contents of that oven shall be rejected.

Reannealing.—Any castings rejected for insufficient annealing may be reannealed once. The reannealed castings shall be inspected and if the remaining test-lugs, or castings broken as specimens, show the castings to be thoroughly annealed, they shall be accepted; if not, they shall be finally rejected.

WORKMANSHIP AND FINISH

Workmanship.—The castings shall conform substantially to the patterns or drawings furnished by the purchaser, and also to gages which may be specified in individual cases. The castings shall be made in a workmanlike manner. A variation of $\frac{1}{8}$ in. per foot will be permitted.

Finish.—The castings shall be free from injurious defects.

MARKING

Marking. — The manufacturer's identification mark and the pattern numbers assigned by the purchaser shall be cast on all castings of sufficient size, in such positions that they will not interfere with the service of the castings.

INSPECTION AND REJECTION

Inspection.—The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the castings ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the castings are being furnished in accordance with these specifications. All tests and inspec-

tion shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

The manufacturer shall be required to keep a record of each melt from which castings are produced, showing tensile strength and elongation of test-specimens cast from such melts. These records shall be available and shown to the inspector whenever required.

Rejection.—Castings which show injurious defects subsequent to their acceptance at the manufacturer's works may be rejected, and, if rejected, shall be replaced by the manufacturer free of cost to the purchaser.

PART VI—DEFINITIONS

General Information

Normalizing.—A uniform heating above the upper critical temperature followed by cooling freely in air.

Annealing.—A uniform heating above the upper critical temperature followed by slow cooling as desired.

Quenching.—The operation of rapidly cooling in a suitable medium.

Drawing.—Reheating after quenching for hardening, to some temperature below the lower limit of the critical range, followed by cooling as desired.

Case-Hardening.—The operation of carburizing steel to a predetermined depth of case and subjecting it to a subsequent heat-treatment.

Carburizing.—The operation of causing the absorption of carbon by steel when heated below its melting point in contact with carbonaceous material.

Case.—The outer portion of a carbonized part that has absorbed carbon from the carburizing medium.

Core.—The inner portion of a carburized part that has not absorbed carbon from the carburizing medium.

Cyaniding.—The operation of case-hardening by which

the carburizing is accomplished by heating the steel in a melted cyanide salt.

Cold-Working.—The operation of forming the metal, without the application of heat, by rolling, hammering, drawing, pressing or other means to obtain accurate size, fine finish or increased strength.

Hot-Working.—The operation of rolling, hammering, pressing or extruding metal which has been made plastic by heating.

Yield-Point.—The load per unit of original cross-section at which a marked increase in the deformation of the specimen occurs without increase of load. It is usually calculated from the load determined by the drop of the beam of the testing machine or by use of dividers.

Tensile-Strength.—The maximum load per unit of original cross-sectional area obtained before rupture.

Percentage Elongation.—The percentage of increase in length of a tension test-specimen after rupture.

Percentage Reduction of Area.—The percentage of decrease of cross-sectional area of a tension test-specimen after rupture.

Shore Hardness.—The reading of a conventional scale determined by the rebound of the hammer of the Shore scleroscope on striking the surface of the specimen.

Brinell Hardness.—The number obtained from the ratio between the load applied on and the spherical area of the impression made by a steel ball forced into the surface of the material tested.

PART VII—TEST-SPECIMENS

S. A. E. STANDARD

S. A. E. Steels shall be purchased on the basis of requirements as to chemical composition, and the specifications provided herein should be used in the purchase of the grades and types of steel covered by each. When the steel user desires physical tests on forged parts, bars or

billets, the test-specimens shall be selected and prepared in accordance with the following standards.

CONSTRUCTION

Tension and bend test-specimens shall be taken from the rolled or forged material, except that in the case of irregularly shaped forgings, they may be taken from a full-size prolongation. Test-specimens shall not be annealed or otherwise treated, except as specified in the following paragraph. Bend tests shall be made cold.

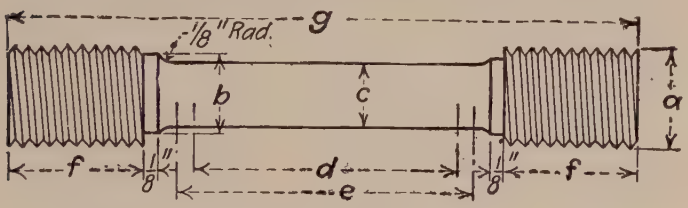


FIG. 100

PROPORTIONAL-SIZE ROUND TENSION TEST-SPECIMEN

Diameter of Stock, In.	½ to ¾	⅜ to ½	¼ to ⅜
a, In.	0.500	0.375	0.250
b, In.	0.391	0.281	0.172
Diameter over Gage-Length (*c*), In.	0.375	0.250	0.125
Gage-Length (*d*), In.	1.500	1.000	0.500
e, In.	1.750	1.250	0.750
f, In. (Approximately)	0.750	0.500	0.375
g, In. (Approximately)	3.625	2.625	1.875

$$\text{Gage-Length, } d = 4.5 \sqrt{\text{Area of Cross-Section}}$$

Tension and bend test-specimens for material that is to be annealed or otherwise treated before use shall, for rolled material, be cut from properly annealed or similarly treated short lengths of the full section of the piece and for forged material from the treated forgings.

The axis of tension and bend test-specimens for rolled

bars and forgings of uniform cross-section of over 1½ in. thickness or diameter and for forgings of irregular sections shall, when practicable, be located at any point midway between the center and the outer surface when solid, and at any point midway between the inner and outer surfaces of the wall when bored, and shall be parallel to the axis of the piece in the direction in which the metal is most drawn out. Round tension test-specimens shall be machined to the form and dimensions shown in Fig. 97. The gage-length and fillets shall be ground or lap-polished free from scratches. The ends shall be of a form to fit the holders of the testing machine in such a way that the load shall be axial. Threaded-ends or self-aligning ball-ends are recommended.

The bend test-specimens shall be ½ in. square in section and not over 6 in. in length with corners rounded to a radius of not over 1/16 in.

The axis of tension test-specimens for rolled bars and forgings of uniform cross-section 1½ in. or under in thickness or diameter shall be machined concentrically from the specimen. Round tension test-specimens may be machined to the form and dimensions shown in Fig. 99 or may be of larger dimensions provided the length of the pull-section conforms to the formula,

$$\text{gage-length, } d = 4.5 \sqrt{\text{area of cross-section.}}$$

The gage-length and fillets shall be ground or lap-polished free from scratches. The ends shall be of a form to fit the holders of the testing machine in such a way that the load shall be axial. Threaded-ends or self-aligning ball-ends are recommended.

Bend test-specimens shall be ½ in. square in section and not over 6 in. in length with corners rounded to a radius of not over 1/16 in.

Round tension test-specimens for rolled bars or forgings of dimensions too small to permit the use of the standard full-size test-specimen, may be machined to the dimensions of the proportional-size round test-specimens

shown in Fig. 100 and the accompanying table. The gage-length and fillets shall be ground or lap-polished free from scratches. The ends shall be of a form to fit the holders of a testing-machine in such a way that the load will be axial. Threaded or self-aligning ball-ends are recommended.

Flat tension and bend test-specimens for plates and shapes shall be of the full thickness of material as rolled and tensile test-specimens shall be machined to the form and dimensions shown in Fig. 98. The gage-width of test-specimens ¼ in. or less in thickness should be equal to five times the thickness, except that in no case shall the width be less than ¾ in. The gage-length should equal 24 times the thickness of the test-specimen, except that in no case shall it be less than 2 in. The gage-length on test-specimens shall be finished on all sides smooth and free from scratches.

Tension test-specimens for malleable castings as specified in that specification shall conform to the shape and dimensions shown in Fig. 99 and shall *not* be machined.

NUMBER OF TESTS

Unless otherwise specified by the purchaser, one tension and one bend test shall be made from each melt; except that if material rolled from one melt differs ⅜ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material.

If any test-specimen shows defective machining or develops flaws, it may be discarded; in which case the manufacturer and the purchaser or his representative shall agree upon the selection of another test-specimen in its stead.

If the percentage of elongation of any tension test-specimen is less than that specified and any part of the fracture is more than ¾ in. from the center of the gage-length of a 2-in. test-specimen or is outside the middle third of the gage-length of an 8-in. test-specimen, as in-

dicated by divider scratches marked on the test-specimen before testing, a retest shall be allowed.

PART VIII—HARDNESS TESTS

Brinell Hardness Test

S. A. E. RECOMMENDED PRACTICE

Test Ball.—The diameter of the ball shall be 10 ± 0.0025 mm. (0.39370 ± 0.00098 in.). The weight applied shall be 3000 kg. (6600 lb.) for 30 sec.

Test Impression.—The average diameter of the impression shall be obtained from two measurements at right angles to each other, made with an instrument having a reading error not over 0.05 mm. (0.001969 in.).

Test-Specimen.—The surface of the specimen shall be free from scratches. The specimen shall be taken deep enough to represent the true composition of the material to be tested, and shall be maintained in a plane normal to the direction of the testing load.

Exceptions.—This test should not be used on soft steels less than ½ in. thick or on areas small enough to permit deflection of the edges of the specimen owing to the flow from the ball depression.

Shore Hardness Test

GENERAL INFORMATION

The Shore hardness number is the reading obtained on an arbitrary scale ranging from 0 to 120, by the rebound of a small diamond-pointed hammer dropped from a fixed height. Two types of instrument are in common use; one in which the rebound is read directly on a vertical scale, and the other on which the reading is registered by the instrument on a recording dial. It is suggested that, unless special means are used to compensate for the variations in mass, form, surface, composition and physical condition of different specimens being tested, the user determine for himself the characteristic readings obtained on his particular product.

IRON AND STEEL SPECIFICATIONS

BRINELL HARDNESS NUMBERS

Diameter of Impression, Mm.	Brinell Hardness Nos. Loads in Kg. 3000	500	Diameter of Impression, Mm.	Brinell Hardness Nos. Loads in Kg. 3000	500	Diameter of Impression, Mm.	Brinell Hardness Nos. Loads in Kg. 3000	500	Diameter of Impression, Mm.	Brinell Hardness Nos. Loads in Kg. 3000	500
2.00	945	158	3.25	352	59	4.50	179	30	5.75	105	18
2.05	899	150	3.30	341	57	4.55	174	29	5.80	103	17
2.10	857	143	3.35	331	55	4.60	170	28	5.85	101	17
2.15	817	136	3.40	321	53	4.65	167	28	5.90	99	17
2.20	780	130	3.45	311	52	4.70	163	27	5.95	97	16
2.25	745	124	3.50	302	50	4.75	159	27	6.00	96	16
2.30	712	119	3.55	293	49	4.80	156	26	6.05	94	16
2.35	682	114	3.60	285	48	4.85	152	25	6.10	92	15
2.40	654	109	3.65	277	46	4.90	149	25	6.15	90	15
2.45	627	104	3.70	269	45	4.95	146	24	6.20	89	15
2.50	602	100	3.75	262	44	5.00	143	24	6.25	87	15
2.55	578	96	3.80	255	42	5.05	140	23	6.30	86	14
2.60	555	93	3.85	248	41	5.10	137	23	6.35	84	14
2.65	534	89	3.90	241	40	5.15	134	22	6.40	83	14
2.70	514	86	3.95	235	39	5.20	131	22	6.45	81	14
2.75	495	83	4.00	229	38	5.25	128	21	6.50	80	13
2.80	478	80	4.05	223	37	5.30	126	21	6.55	78	13
2.85	461	77	4.10	217	36	5.35	123	21	6.60	77	13
2.90	444	74	4.15	212	35	5.40	121	20	6.65	75	13
2.95	429	72	4.20	207	34	5.45	118	20	6.70	74	12
3.00	415	69	4.25	201	34	5.50	116	19	6.75	73	12
3.05	401	67	4.30	197	33	5.55	114	19	6.80	72	12
3.10	388	65	4.35	192	32	5.60	111	19	6.85	70	12
3.15	375	63	4.40	187	31	5.65	109	18	6.90	69	12
3.20	363	61	4.45	183	31	5.70	107	18	6.95	68	11
									7.00	67	11

The scleroscope values shown in the accompanying charts of physical properties are average values obtained with the bulb or vertical-scale type of instrument under the conditions described in the Notes, the specimens tested having carefully polished, level surfaces, which are essential in obtaining satisfactory results.

PART IX—GENERAL HEAT-TREATMENTS

General Information

In applying the detailed heat-treatments as outlined hereinafter it is recommended, in order to obtain uniform physical properties, that the final quench be made from the lowest temperature that will develop the maximum physical properties, bearing in mind that with thinner sections lower temperatures are required than with thicker sections.

CASE-HARDENING

The process of carburizing as considered in these notes refers to the dry or pack method and does not take into consideration carburizing by the liquid or gaseous methods. The last two methods have extensive application but the operations depend to such a large extent on individual conditions such as size, shape and use for which these are intended that they cannot be covered by these general notes.

The procedure after carburizing is usually divided into two methods.

(1) Quenching directly from the box,

(2) Cooling slowly in the box.

The first method prevents the formation of a cementite network and large grain-growth. The second method tends in many instances to lessen distortion but does not prevent the formation of a cementite network and large grain-growth. In Heat-Treatment V, the first reheat, Operation 3, is applied to refine the core and has a beneficial effect on the case. These two general methods are sub-divided into specific types of heat-treatments that are

applicable for parts of various compositions, shapes, uses and importance.

In case-hardening heat-treatments the drawing operation is not always used in commercial practice, but it is recommended in all cases as being in accord with the best metallurgical practice.

PHYSICAL PROPERTIES AND HEAT-TREATMENTS

In interpreting the charts of physical properties the following considerations should always be borne in mind.

The charts have been made as valuable as possible to the engineer by indicating what can be expected as the average product of a given composition when treated in the specific manner in 1½-in. sections. Generally on sizes larger than 1½ in., lower values will prevail and on sizes smaller than 1½ in., higher values will prevail. At the same time the data for the charts have been chosen so as

CASE-HARDENING HEAT-TREATMENTS

Operation No.	I	II	III	IV	V
1	Carburize	Carburize	Carburize	Carburize	Carburize
2	Quench	Quench	Quench	Cool in box	Cool in box
3	Draw	Reheat	Reheat	Reheat	Reheat
4		Quench	Quench	Quench	Quench
5		Draw	Reheat	Draw	Reheat
6			Quench		Quench
7			Draw		Draw

HARDENING AND TOUGHENING HEAT-TREATMENTS

Operation No.	VI	VII	VIII
1	Heat	Normalize	Normalize
2	Quench	Reheat	Reheat
3	Draw	Quench	Cool in furnace
4		Draw	Machine
5			Reheat
6			Quench
7			Draw

to protect makers of heat-treated stock and parts from unreasonable demands.

For the sake of simplicity it has seemed advisable to use only average minimum figures for tensile-strength, yield-point, reduction of area and elongation, based on the following considerations, heat-treatment being constant:

(1) The lowest yield-points and tensile-strengths are produced with steels at the bottom of a given range in carbon.

(2) The lowest reductions in area and elongations are produced with steels at the top of a given range in carbon.

Thus, for Steel 1035, the average minimum yield-points and tensile-strengths are given as of a steel containing 0.30% carbon; average minimum reductions of area and elongations as of a steel containing 0.40% carbon.

The figures for hardness are conventional averages for the whole range of compositions within any given specification.

The charts include treatments and conservative physical tests on all S. A. E. Steels for which such charts have been prepared. For these charts the following applies:

(1) They indicate the physical properties which may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars of 1½-in. diameter or square.

(2) Heat-treatments given in the charts apply to rolled bars that were normalized or otherwise treated prior to heating and quenching as shown on individual charts.

(3) Test-bars 0.505 in. diameter and 2 in. long, machined from rolled bars after final treatment and tested under normal commercial conditions.

(4) Brinell and scleroscope readings were taken at a distance from the center equal to half

the radius and are not to be compared with surface readings on heat-treated bars or parts.

CARBON STEELS

S. A. E. Steels 1010 and 1015

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CHEMICAL COMPOSITION IN PERCENTAGE

Steel	1010	1015
Carbon	0.05–0.15	0.10–0.20
Manganese	0.30–0.60	0.30–0.60
Phosphorus	0.045 max.	0.045 max.
Sulphur	0.05 max.	0.05 max.

These steels are commonly used for tubing and pressed-steel parts of many varieties. They are soft and ductile and will stand much deformation without cracking.

In a natural or annealed condition, these steels have low tensile-strength and should not be used where much strength is required. They are considerably stronger after cold-working; that is, the yield-point is raised by such working. This is important in view of the fact that many parts are used in cold-worked condition.

These compositions, when in the natural or annealed condition, should have the following approximate physical properties:

Yield-Point, lb. per sq. in.....28,000 to 36,000
Elongation of 2 In., per cent... 40 to 30
Reduction of Area, per cent... 65 to 55

It should be borne in mind that when these steels in cold-worked condition are heated for bending, brazing, welding or such operations the yield-point returns to that

which is characteristic of the annealed or hot-worked material. This applies also to all materials the yield-point of which is increased by cold-working.

These steels do not machine freely. They will tear badly in turning, threading and broaching operations. It is possible, by quenching them in water from 1700° F., no draw being required, to improve their machining qualities over those in the annealed condition. Such heat-treatment, however, produces very little increase in strength. These steels can be used for case-hardening, Heat-Treatment I being used when the refinement of the case is not important.

Heat-Treatment II is recommended when maximum hardness only is required and distortion is not important. When maximum hardness of case and refinement of both the case and core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the case and the least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core is desired, distortion not being important, Heat-Treatment V may be used.

Heat-Treatment 1010-*I and* 1015-*I*

(1) Carburize at 1650 to 1700° F.
(2) Quench
(3) Draw at 250 to 500° F. is recommended

Heat-Treatment 1010-*II and* 1015-*II*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box
(3) Reheat to 1400 to 1450° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 1010-*III and* 1015-*III*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box
(3) Reheat to 1650 to 1700° F.
(4) Quench

(5) Reheat to 1400 to 1450° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 1010-*IV and* 1015-*IV*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1400 to 1450° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 1010-*V and* 1015-*V*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1650 to 1700° F.
(4) Quench
(5) Reheat to 1400 to 1450° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

S. A. E. Steel 1020

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.045 max.
Sulphur	0.05 max.

This steel is known to the trade as 0.20 carbon open-hearth steel, and often as machine steel. It forges well and machines better than S. A. E. Steels 1010 and 1015, but should not be considered as screw-machine stock. It can be used for a very large variety of forged, machined

and case-hardened automotive parts where strength is not paramount.

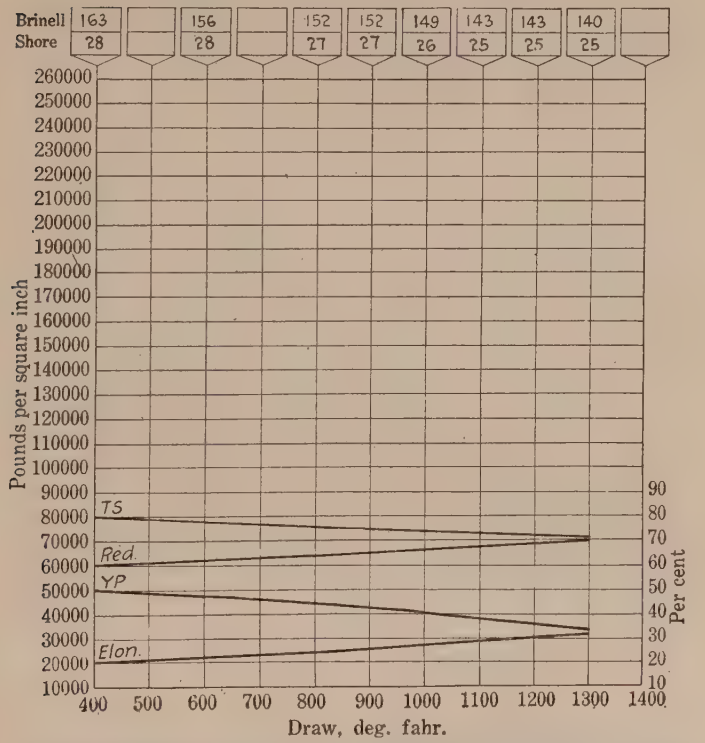
Steel of this quality can be drawn into tubes and cold-rolled into forms and shapes for automotive parts. It can be also safely used interchangeably with S. A. E. Steels 1010 and 1015 for cold-worked shapes that do not require deep drawing.

Chart for S. A. E. Steel 1020

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.045 max.
Sulphur	0.05 max.

Quenched at 1600 to 1650° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

When cold-worked, this steel will have a yield-point of 40,000 to 80,000 lb. per sq. in. in round sections not over ½ in. in diameter or in sheets or flats ¼ in. thick. Heat-treatment of this steel produces a desirable refinement of grain after rolling or forging. The following heat-treatment will often help the machining qualities of hot-rolled and forged stock:

Heat-Treatment 1020-*VI*

(1) Heat to 1575 to 1675° F.
(2) Quench in water
(3) Draw to required hardness

Case-hardening is the most important heat-treatment for this quality of steel. The particular case-hardening treatment depends upon the importance of the part to be treated and its shape and size. When hardness only is required, such parts may be subjected to Heat-Treatment II; when maximum hardness of the case and refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used; when a refined case and minimum distortion are required, Heat-Treatment IV should be used; when maximum refinement of both the case and the core is required Heat-Treatment V should be used.

When this steel is used for gears for which a high degree of accuracy and considerable strength are required, it is recommended that the carburizing operation be preceded by normalizing at 1650 to 1750° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

Heat-Treatment 1020-*I*

(1) Carburize at 1650 to 1700° F.
(2) Quench
(3) Draw at 250 to 500° F. is recommended

Heat-Treatment 1020-*II*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box
(3) Reheat to 1400 to 1450° F.

(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 1020-*III*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box
(3) Reheat to 1600 to 1650° F.
(4) Quench
(5) Reheat to 1400 to 1450° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 1020-*IV*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1400 to 1450° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 1020-*V*

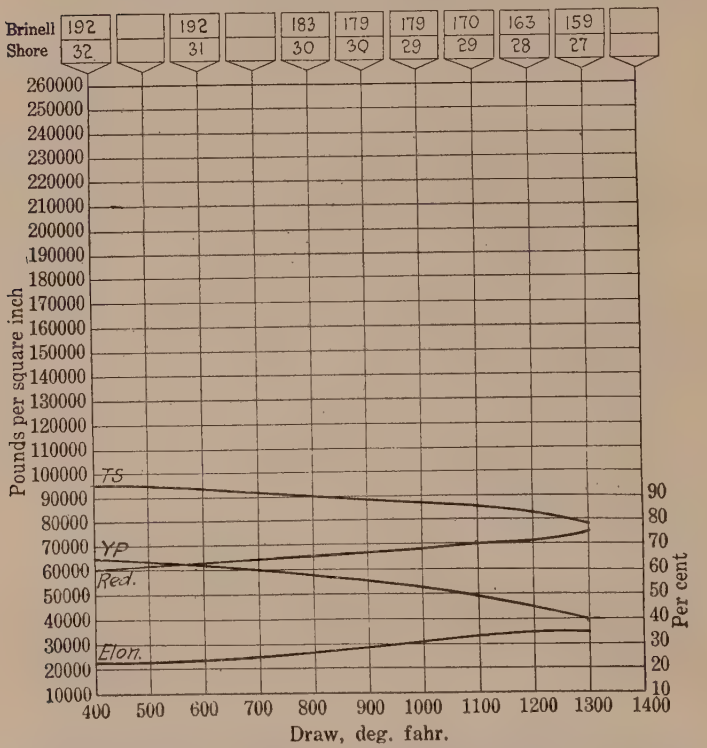
(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1600 to 1650° F.
(4) Quench
(5) Reheat to 1400 to 1450° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

Chart for S. A. E. Steel 1025

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.20–0.30
Manganese	0.50–0.80
Phosphorus	0.045 max.
Sulphur	0.05 max.

Quenched at 1575 to 1650° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to* 1½-*in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-*in. diameter or square, this chart does not apply.*

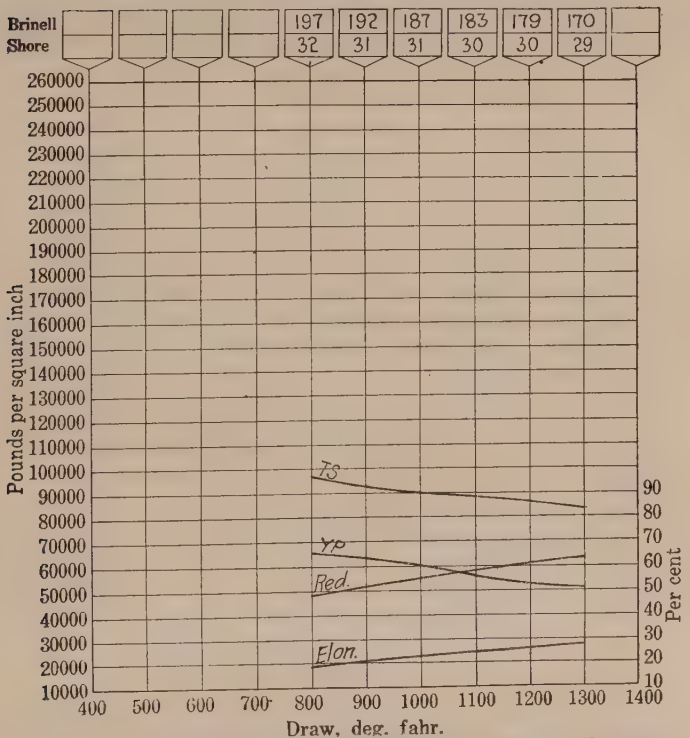
Chart for S. A. E. Steel 1035

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.30–0.40
Manganese	0.50–0.80
Phosphorus	0.045 max.
Sulphur	0.05 max.

Quenched at 1525 to 1575° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to* 1½*-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½*-in. diameter or square, this chart does not apply.*

S. A. E. Steels 1025 and 1030

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CHEMICAL COMPOSITION IN PERCENTAGE

Steel	1025	1030
Carbon	0.20–0.30	0.25–0.35
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.045 max.	0.045 max.
Sulphur	0.05 max.	0.05 max.

These steels will respond to heat-treatment better than Steel 1020. They can be used, therefore, for forged, machined or cold-worked parts requiring slightly higher physical properties than are obtainable with Steel 1020 and will have better machining qualities.

These steels should not be used for parts that are to be carburized. Heat-Treatment VI is recommended.

Heat-Treatment 1025-*VI and* 1030-*VI*

(1) Heat to 1575 to 1650° F.
(2) Quench in water
(3) Draw to required hardness

Where the maximum of uniformity in machining and in physical properties is desired, Heat-Treatment VII is recommended.

Heat-Treatment 1025-*VII and* 1030-*VII*

(1) Normalize at 1700 to 1800° F.
(2) Heat to 1575 to 1650° F.
(3) Quench in water
(4) Draw to required hardness

S. A. E. Steels 1035 and 1040

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CHEMICAL COMPOSITION IN PERCENTAGE

Steel	1035	1040
Carbon	0.30–0.40	0.35–0.45
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.045 max.	0.045 max.
Sulphur	0.05 max.	0.05 max.

These are medium carbon steels possessing good machining properties and are suitable for small and medium sizes of plain carbon-steel forgings where moderate physical properties are desired. For general purposes Heat-Treatment VI is satisfactory.

Heat-Treatment 1035-*VI and* 1040-*VI*

(1) Heat to 1525 to 1575° F.
(2) Quench
(3) Draw to required hardness

Where maximum development of physical properties is desired as in the larger sizes of forgings Heat-Treatment VII is recommended.

Heat-Treatment 1035-*VII and* 1040-*VII*

(1) Normalize at 1650 to 1750° F.
(2) Heat to 1525 to 1575° F.
(3) Quench
(4) Draw to required hardness

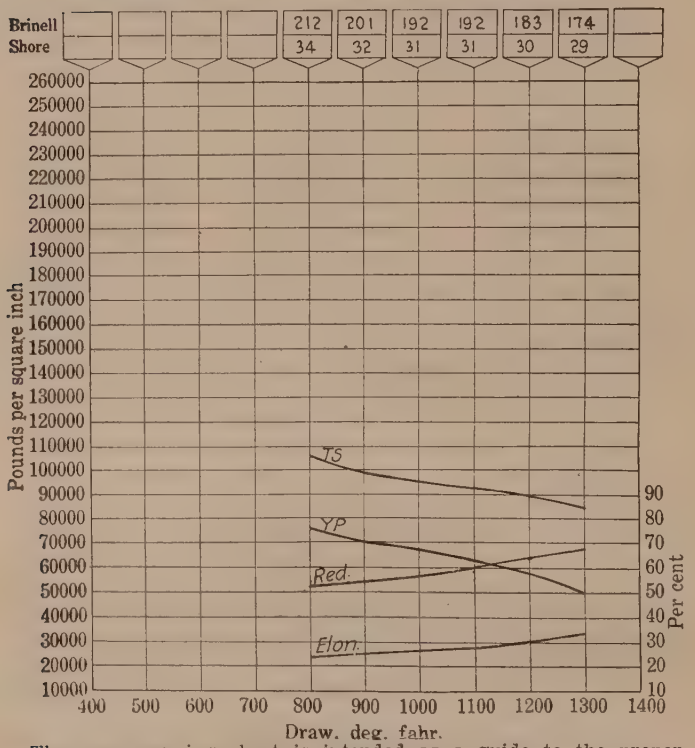
Chart for S. A. E. Steel 1035

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.30–0.40
Manganese	0.50–0.80
Phosphorus	0.045 max.
Sulphur	0.05 max.

Quenched at 1525 to 1575° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

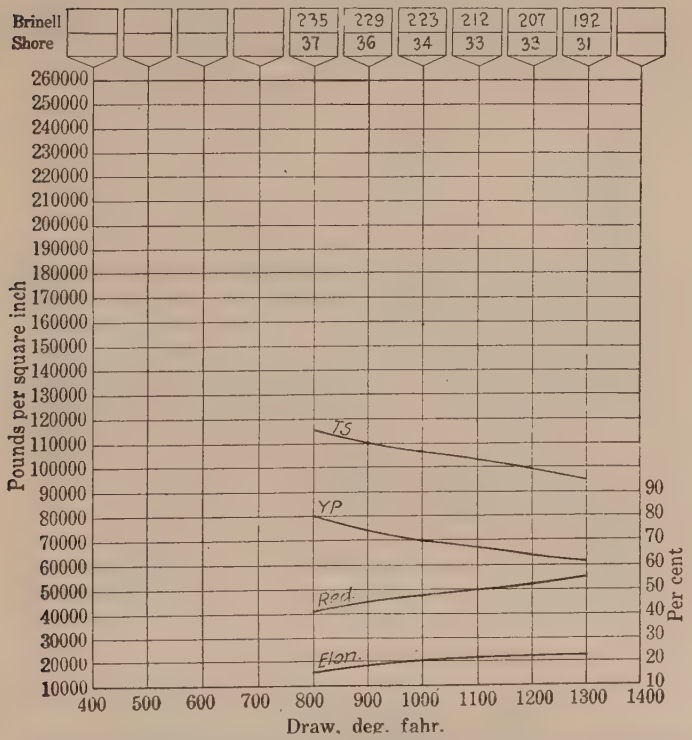
Chart for S. A. E. Steel 1045

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.40–0.50
Manganese	0.50–0.80
Phosphorus	0.045 max.
Sulphur	0.05 max.

Quenched at 1475 to 1525° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

S. A. E. Steels 1045, 1046 and 1050

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CHEMICAL COMPOSITION IN PERCENTAGE

Steel	1045	1046	1050
Carbon	0.40–0.50	0.40–0.50	0.45–0.55
Manganese	0.50–0.80	0.30–0.50	0.50–0.80
Phosphorus	0.045 max.	0.045 max.	0.045 max.
Sulphur	0.05 max.	0.05 max.	0.05 max.

These are medium carbon steels intended for the larger sizes of plain carbon-steel forgings in automotive construction. They can also be used for a wide range of parts machined from bar stock.

Steel 1046 is the same as Steel 1045 except for a lower manganese content and is intended for gears that are to be water-quenched.

For general purposes Heat-Treatment VI will produce the desired physical properties.

Heat-Treatment 1045-*VI*, 1046-*VI and* 1050-*VI*

(1) Heat to 1500 to 1550° F.

(2) Quench in oil or water, depending upon size and shape of part

(3) Draw to required hardness

Where maximum development of physical properties is desired, Heat-Treatment VII is recommended.

Heat-Treatment 1045-*VII*, 1046-*VII and* 1050-*VII*

(1) Normalize at 1600 to 1700° F.

(2) Reheat to 1475 to 1525° F.

(3) Quench in oil or water, depending upon size and shape of part

(4) Draw to required hardness

For parts such as gears that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 1045-*VIII*, 1046-*VIII and* 1050-*VIII*

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1400 to 1450° F.
(3) Cool in furnace
(4) Machine
(5) Reheat to 1475 to 1525° F.
(6) Quench
(7) Draw to required hardness

S. A. E. Steel 1095

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CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.90–1.05
Manganese	0.25–0.50
Phosphorus	0.04 max.
Sulphur	0.05 max.

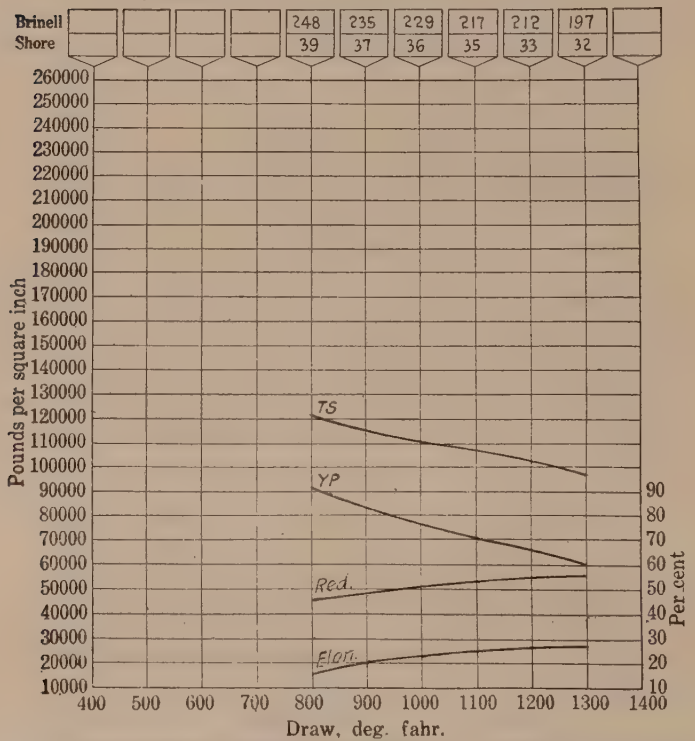
Chart for S. A. E. Steel 1045

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.40–0.50
Manganese	0.50–0.80
Phosphorus	0.045 max.
Sulphur	0.05 max.

Quenched at 1475 to 1525° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

This steel is used chiefly in leaf-springs and occasionally in certain coiled springs. The heat-treatment of such parts is dependent upon the method of manufacture.

For those cases where the user desires to heat-treat this material in plain or simple shapes other than leaf-springs, Heat-Treatment VI is recommended.

Heat-Treatment 1045-*VI*

(1) Heat to 1400 to 1450° F.
(2) Quench in oil, water or brine, depending on size and shape of part
(3) Draw to required hardness

NICKEL STEELS

S. A. E. Steel 2315

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.10–0.20
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

This steel is intended primarily for case-hardening. Parts made from it may be subjected to Heat-Treatment II when maximum hardness only is required and distortion is not important; to Heat-Treatment III when maximum hardness of the case and maximum refinement of both the case and the core are desired, distortion again being unimportant; to Heat-Treatment IV when hardness,

refinement of the case and the least possible distortion are required; and to Heat-Treatment V when refinement of both the case and the core is desired, distortion not being important.

When these steels are used for gears for which a high degree of accuracy and strength is required, it is recommended that the carburizing operation be preceded by normalizing at 1650 to 1750° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

Heat-Treatment 2315-*II*

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1350 to 1400° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 2315-*III*

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1350 to 1400° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

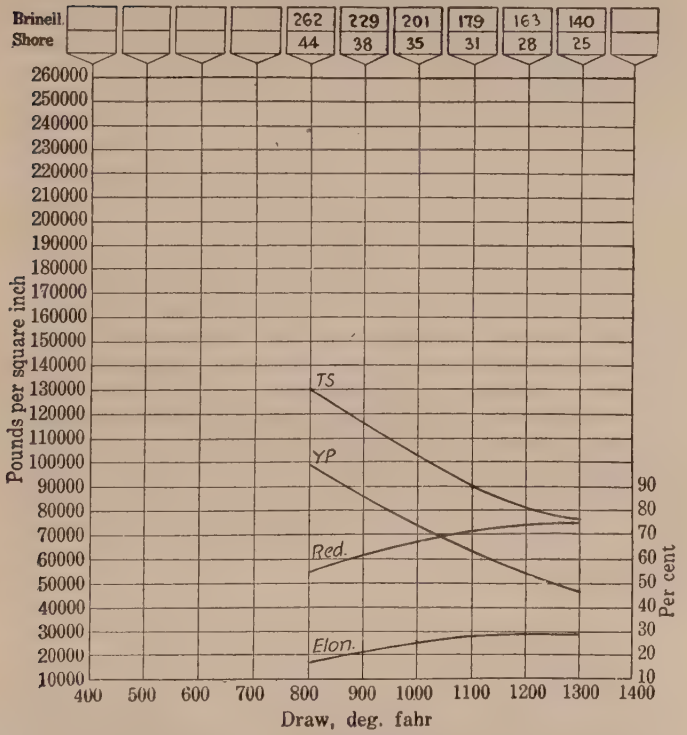
Chart for S. A. E. Steel 2320

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

Normalized at 1650 to 1700° F.,
Quenched at 1475 to 1525° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardness are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

Heat-Treatment 2315-*IV*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1375 to 1425° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 2315-*V*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1350 to 1400° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

S. A. E. Steel 2320

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CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

Steel 2320 is not recommended for case-hardening except for massive parts because of the sacrifice to ductility and support of the core resulting from the higher carbon. Subsequent to carbonizing, great care must be exercised in treatments to minimize brittleness of the core.

Carburized parts made from this steel may be subjected to Heat-Treatment II when maximum hardness only is required and distortion is not important. When maximum hardness of the case and distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the case and least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and core is desired, distortion not being important, Heat-Treatment V should be used. When these steels are used for gears for which a high degree of accuracy and strength is required, it is recommended that the carburizing operation be preceded by normalizing at 1650 to 1750° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

Heat-Treatment 2320-*II*

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1350 to 1400° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

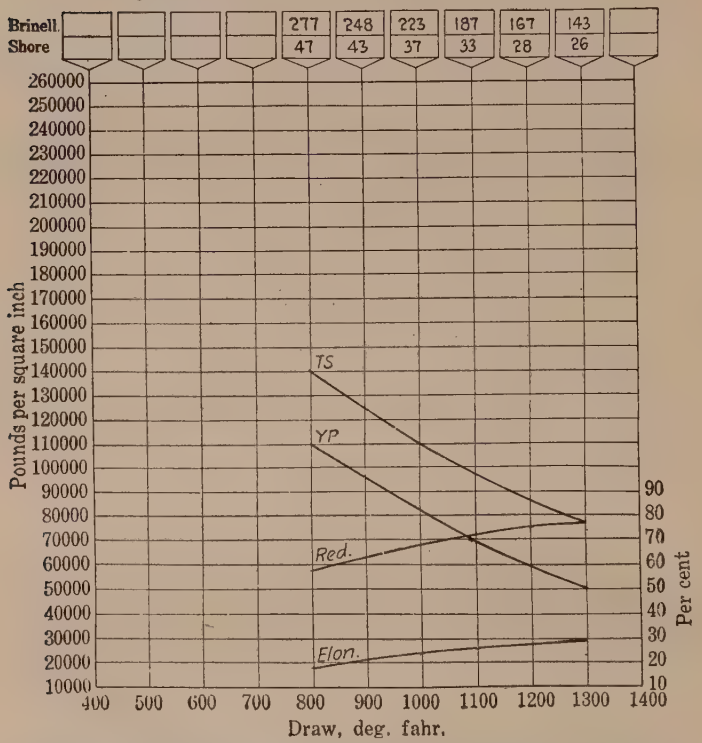
Chart for S. A. E. Steel 2320

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

Normalized at 1650 to 1700° F.,
Quenched at 1475 to 1525° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to* 1½*-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½*-in. diameter or square, this chart does not apply.*

Heat-Treatment 2320-III

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1350 to 1400° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 2320-IV

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1375 to 1425° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 2320-V

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1350 to 1400° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 2320-VI

(1) Heat to 1475 to 1525° F.
(2) Quench
(3) Draw to required hardness

For structural purposes forged parts should be given Heat-Treatment VII which will develop the desired physical properties.

Heat-Treatment 2320-VII

(1) Normalize at 1650 to 1750° F.
(2) Heat to 1475 to 1525° F.
(3) Quench
(4) Draw to required hardness

S. A. E. Steels 2330 and 2335

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steels	2330	2335
Carbon	0.25–0.35	0.30–0.40
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.045 max.	0.045 max.
Nickel	3.25–3.75	3.25–3.75

These steels are primarily for heat-treated automotive parts when considerable strength and toughness are sought. *They should not be case-hardened.*

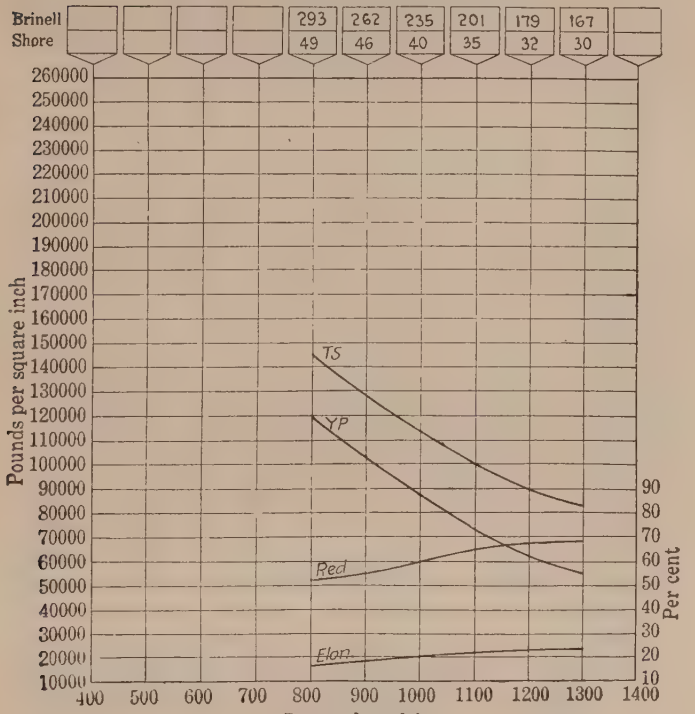
Chart for S. A. E. Steel 2330

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.25–0.35
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

Normalized at 1650 to 1750° F.
Quenched at 1450 to 1500° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

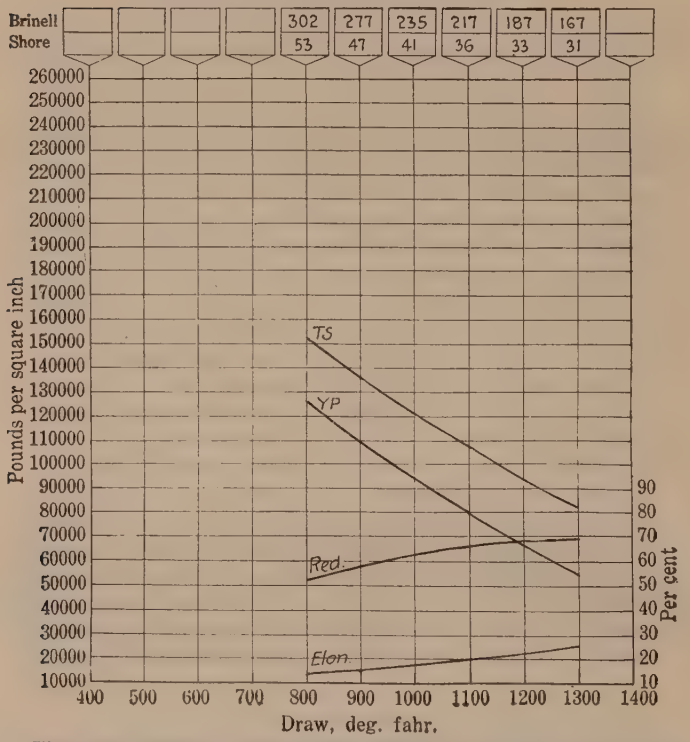
Chart for S. A. E. Steel 2330

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.25–0.35
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

Normalized at 1625 to 1725° F.
Quenched at 1450 to 1500° F. in *water.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 2330-VI and 2335-VI

(1) Heat to 1450 to 1500° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 2330-VII and 2335-VII

(1) Normalize at 1650 to 1750° F.
(2) Heat to 1450 to 1500° F.
(3) Quench
(4) Draw to required hardness

S. A. E. Steels 2340 and 2345

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steels	2340	2345
Carbon	0.35–0.45	0.40–0.50
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.045 max.	0.045 max.
Nickel	3.25–3.75	3.25–3.75

These nickel steels are not widely used, but are available for certain purposes, the carbon content being higher

than generally used, greater hardness is obtained by quenching and as increased brittleness accompanies the greater hardness, the heat-treatments given must be modified to meet such conditions.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 2340-*VI and* 2345-*VI*

(1) Heat to 1425 to 1475° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 2340-*VII and* 2345-*VII*

(1) Normalize at 1625 to 1725° F.
(2) Heat to 1425 to 1475° F.
(3) Quench
(4) Draw to required hardness

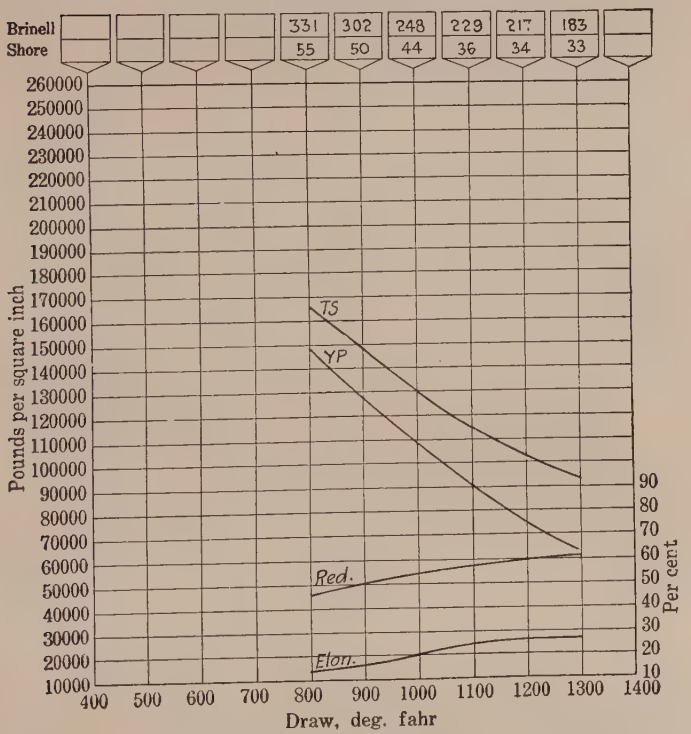
For parts that are to be machined after forging and before heat-treatment, Heat-Treatment VIII is recommended.

Chart for S. A. E. Steel 2340

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.35–0.45
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

Normalized at 1625 to 1725° F.
Quenched at 1425 to 1475° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

Heat-Treatment 2345-VIII

(1) Normalize at 1625 to 1675° F.
(2) Reheat to 1400 to 1450° F.
(3) Cool in furnace
(4) Machine
(5) Reheat to 1425 to 1475° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 2350

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.45–0.55
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	3.25–3.75

This steel is provided to meet the requirements of gear manufacturers for gears of large section.

For parts, such as gears, that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 2350-VIII

(1) Normalize at 1600 to 1650° F.
(2) Reheat to 1375 to 1425° F.
(3) Cool in furnace
(4) Machine

(5) Reheat to 1400 to 1450° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 2512

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.17 max.
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	4.50–5.25

This steel is used for case-hardened parts that require an exceptionally tough core after heat-treatment.

When it is used for gears for which a high degree of accuracy and considerable strength are required, it is recommended that the carburizing operation be preceded by either a normalizing treatment or a quench and drawing operation, which will improve the structure and machinability and tend to reduce the distortion caused by subsequent treatments.

When it is necessary to machine parts made of this steel after carburizing, the nickel content should be maintained as near the lower limit as possible.

For parts that are to be carburized Heat-Treatment IV is recommended.

Heat-Treatment 2512-*IV*

(1) Carburize at 1600 to 1650° F.

(2) Cool in box
(3) Reheat to 1400 to 1450° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 2512-*V*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1350 to 1400° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

NICKEL-CHROMIUM STEELS

S. A. E. Steels 3115 and 3120

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	3115	3120
Carbon	0.10–0.20	0.15–0.25
Manganese	0.30–0.60	0.30–0.60
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.045 max.
Nickel	1.00–1.50	1.00–1.50
Chromium	0.45–0.75	0.45–0.75

These steels are intended primarily for case-hardening but can also be used for structural parts with suitable heat-treatments such as VI or VII.

Carburized parts made from these steels may be subjected to Heat-Treatment II when hardness only is required and distortion is not important. When maximum hardness of the case and maximum refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the case and the least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core is desired, distortion not being important, Heat-Treatment V should be used.

Steel 3120 is not recommended for case-hardening except for massive parts because of the sacrifice to ductility and support of the core resulting from the higher carbon. Subsequent to carburizing, great care must be exercised in treatments to minimize the brittleness of the core.

When these steels are used for gears for which a high degree of accuracy and considerable strength are required, it is recommended that the carburizing operation be preceded by normalizing at 1650 to 1750° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

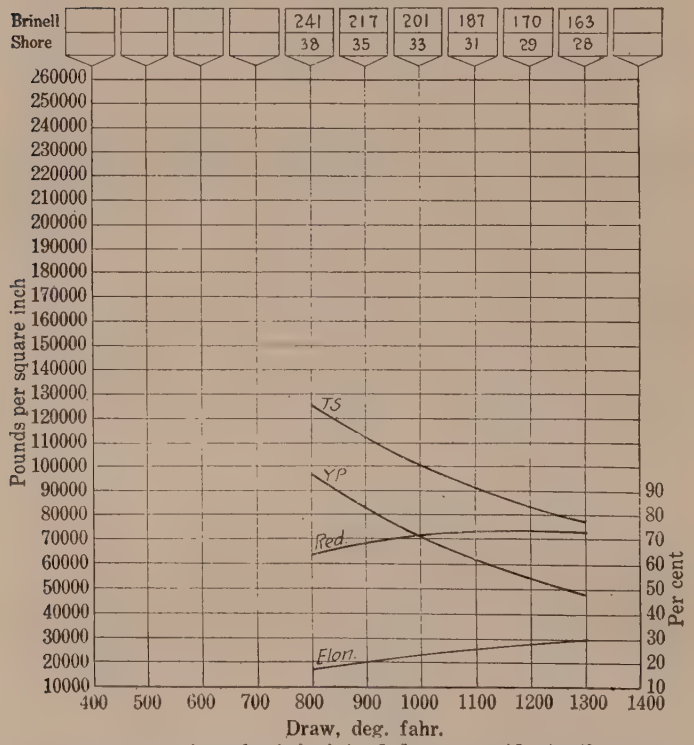
Chart for S. A. E. Steel 3120

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	1.00–1.50
Chromium	0.45–0.75

Quenched at 1575 to 1625° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

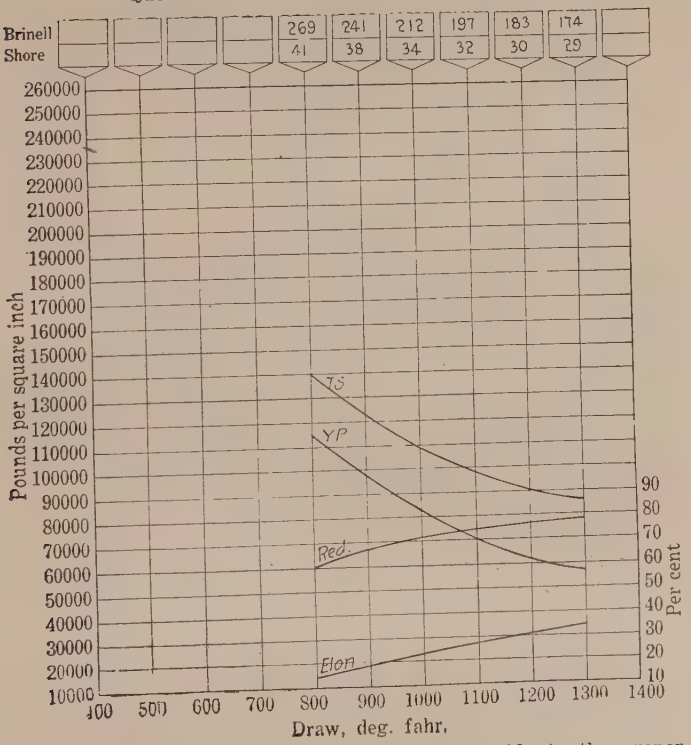
Chart for S. A. E. Steel 3120

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	1.00–1.50
Chromium	0.45–0.75

Quenched at 1575 to 1625° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

Heat-Treatment 3115-*II and* 3120-*II*

(1) Carburize at 1625 to 1675° F.
(2) Quench from box in oil
(3) Reheat to 1400 to 1450° F.
(4) Quench
(5) Draw to 250 to 500° F. is recommended

Heat-Treatment 3115-*III and* 3120-*III*

(1) Carburize at 1625 to 1675° F.
(2) Quench from box in oil
(3) Reheat to 1525 to 1575° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 3115-*IV and* 3120-*IV*

(1) Carburize at 1625 to 1675° F.
(2) Cool in box
(3) Reheat to 1400 to 1450° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3115-*V and* 3120-*V*

(1) Carburize at 1625 to 1675° F.
(2) Cool in box
(3) Reheat to 1525 to 1575° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment

for all forgings, but the desired physical properties of bar stock may be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3120-*VI*

(1) Heat to 1575 to 1625° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 3120-*VII*

(1) Normalize at 1650 to 1750° F.
(2) Heat to 1575 to 1625° F.
(3) Quench
(4) Draw to required hardness

S. A. E. Steels 3125 and 3130

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	3125	3130
Carbon	0.20–0.30	0.25–0.35
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.045 max.	0.045 max.
Nickel	1.00–1.50	1.00–1.50
Chromium	0.45–0.75	0.45–0.75

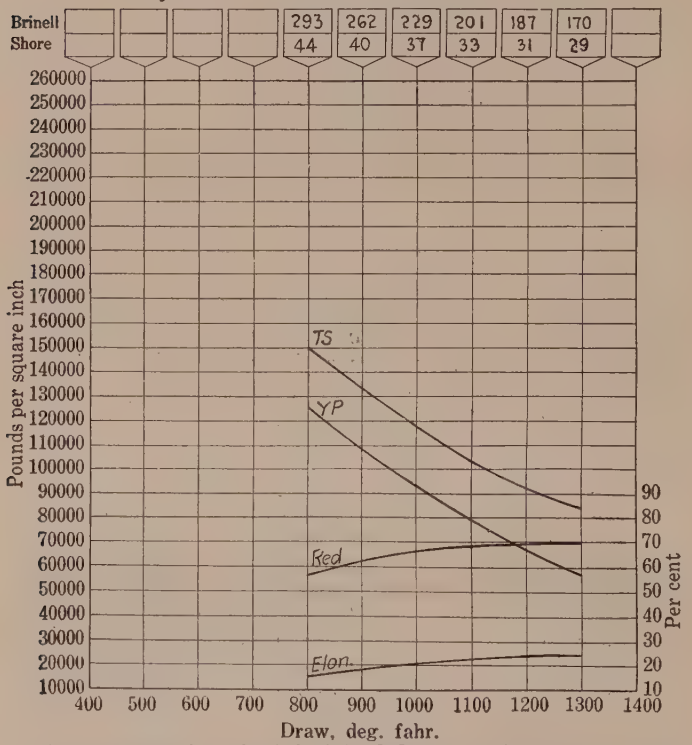
Chart for S. A. E. Steel 3130

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.25–0.35
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	1.00–1.50
Chromium	0.45–0.75

Normalized at 1650 to 1750° F.
Quenched at 1500 to 1550° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

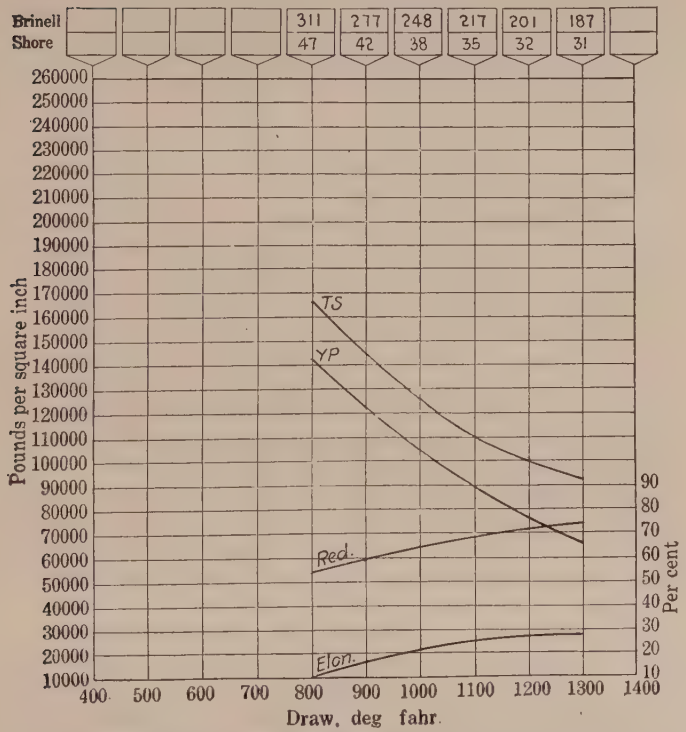
Chart for S. A. E. Steel 3130

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.25–0.35
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	1.00–1.50
Chromium	0.45–0.75

Normalized at 1650 to 1750° F.
Quenched at 1500 to 1550° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

These steels may be used interchangeably with Steels 2330 and 2335 for heat-treated automotive parts requiring greater strength and toughness than provided by plain carbon steel. *They should not be used for carburizing.*

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3125-*VI and* 3130-*VI*

(1) Heat to 1500 to 1550° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 3125-*VII and* 3130-*VII*

(1) Normalize at 1650 to 1750° F.
(2) Heat to 1500 to 1550° F.
(3) Quench
(4) Draw to required hardness

S. A. E. Steels 3135 and 3140

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	3135	3140
Carbon	0.30–0.40	0.35–0.45
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.045 max.	0.045 max.
Nickel	1.00–1.50	1.00–1.50
Chromium	0.45–0.75	0.45–0.75

These steels may also be used interchangeably with Steels 2340 and 2345 for heat-treated automotive forgings requiring greater strength and toughness than are obtainable with plain carbon steel.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3135-*VI and* 3140-*VI*

(1) Heat to 1475 and 1525° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 3135-*VII and* 3140-*VII*

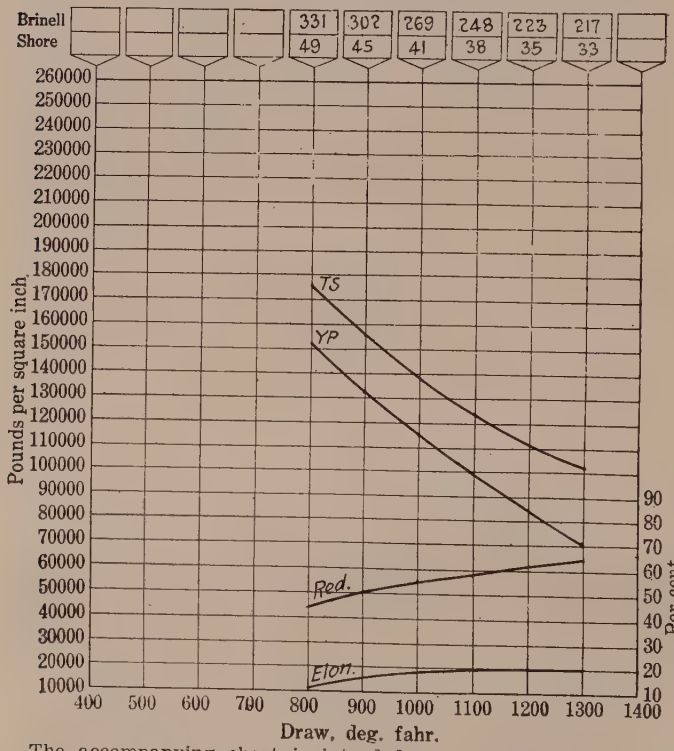
(1) Normalize at 1625 to 1725° F.
(2) Heat to 1475 to 1525° F.
(3) Quench in oil
(4) Draw to required hardness

Chart for S. A. E. Steel 3140

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.35–0.45
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Nickel	1.00–1.50
Chromium	0.45–0.75

Normalized at 1600 to 1700° F.
Quenched at 1475 to 1525° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

S. A. E. Steels 3215 and 3220

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	3215	3220
Carbon	0.10–0.20	0.15–0.25
Manganese	0.30–0.60	0.30–0.60
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Nickel	1.50–2.00	1.50–2.00
Chromium	0.90–1.25	0.90–1.25

These steels are intended primarily for case-hardened parts that require a greater strength of core than is obtainable in Steels 3115 and 3120. They can also be used for structural parts after suitable heat-treatment. Their higher chromium content, which causes deeper penetration of the effect of heat-treatment, makes them more suitable for use in heavy sections over 1½-in. diameter than Steels 3115 and 3120.

Carburized parts made from these steels may be subjected to Heat-Treatment II when hardness only is required and distortion is not important. When maximum hardness of the case and maximum refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the core and least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core are desired, distortion not being important, Heat-Treatment V should be used.

Steel 3220 is not recommended for case-hardening except for massive parts because of the sacrifice to ductility and support resulting from the higher carbon. Subsequent to carburizing, great care must be exercised in treatments to minimize the brittleness of the core.

When these steels are used for gears for which a high degree of accuracy and considerable strength are required, it is recommended that the carburizing operation be preceded by normalizing at 1650 to 1750° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

Heat-Treatment 3215-*II and* 3220-*II*

(1) Carburize at 1625 to 1675° F.
(2) Quench from box in oil
(3) Reheat to 1375 to 1425° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3215-*III and* 3220-*III*

(1) Carburize at 1625 to 1675° F.
(2) Quench from box in oil
(3) Reheat to 1525 to 1575° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

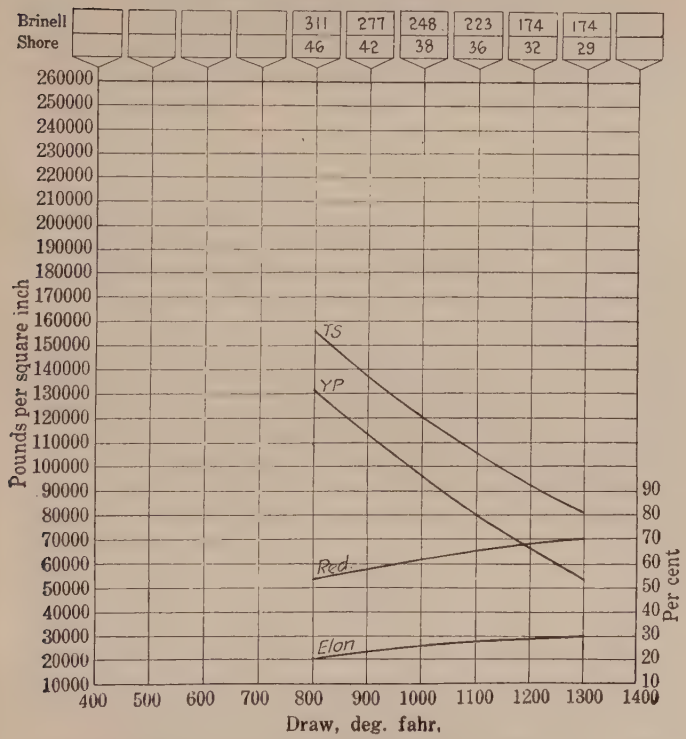
Chart for S. A. E. Steel 3220

QUENCHED IN OIL

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

Normalized at 1625 to 1725° F.
Quenched at 1500 to 1600° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

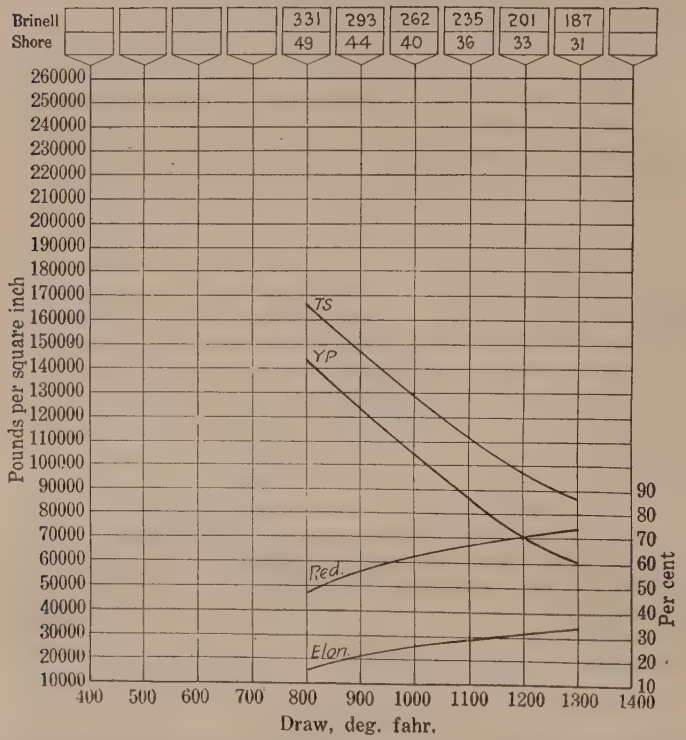
Chart for S. A. E. Steel 3220

QUENCHED IN WATER

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

Normalized at 1625 to 1725° F.
Quenched at 1550 to 1600° F. in *water*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to* 1½*-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½*-in. diameter or square, this chart does not apply.*

Heat-Treatment 3215-IV and 3220-IV

(1) Carburize at 1625 to 1675° F.
(2) Cool in box
(3) Reheat to 1375 to 1425° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3215-V and 3220-V

(1) Carburize at 1625 to 1675° F.
(2) Cool in box
(3) Reheat to 1525 to 1575° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3220-VI

(1) Heat to 1525 to 1575° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 3220-VII

(1) Normalize at 1625 to 1725° F.
(2) Heat to 1525 to 1575° F.
(3) Quench
(4) Draw to required hardness

S. A. E. Steel 3230

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.25–0.35
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

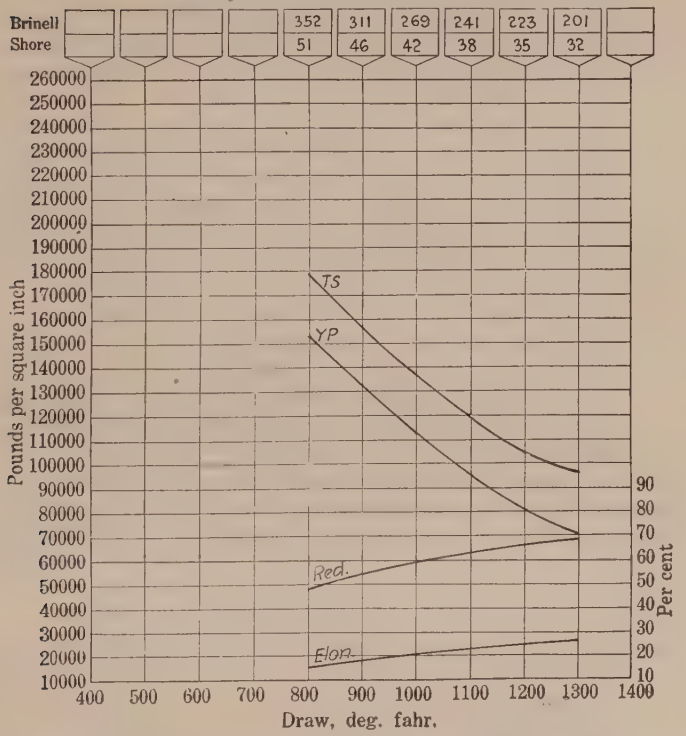
This steel is intended for heat-treated, machined and forged parts that are to be subjected to severe service conditions that demand higher physical properties than are obtainable with Steels 2330, 2335, 3125 or 3130. This steel also responds to heat-treatment more sharply and uniformly in large sections over 1½ in. in diameter than Steels 2330, 2335, 3125 or 3130.

Chart for S. A. E. Steel 3230

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.25–0.35
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

Normalized at 1625 to 1725° F.
Quenched at 1500 to 1550° F. in *oil*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

Heat-Treatment 3230-*VI*

(1) Heat to 1500 to 1550° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 3230-*VII*

(1) Normalize at 1625 to 1725° F.
(2) Heat to 1500 to 1550° F.
(3) Quench in oil
(4) Draw to required hardness

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

S. A. E. Steel 3240

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.35–0.45
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

This steel is intended for heat-treated forgings and

machined parts that are to be subjected to service conditions demanding greater strength than is obtainable with Steels 2340, 2345, 3135 or 3140. It is also more suitable for large sections of over 1½-in. in diameter than any of those steels because of the greater penetration of the effect of heat-treatment resulting from the increased chromium content. This steel is not recommended for gears.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3240-*VI*

(1) Heat to 1475 to 1525° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 3240-*VII*

(1) Normalize at 1625 to 1725° F.
(2) Reheat to 1475 to 1525° F.
(3) Quench in oil
(4) Draw to required hardness

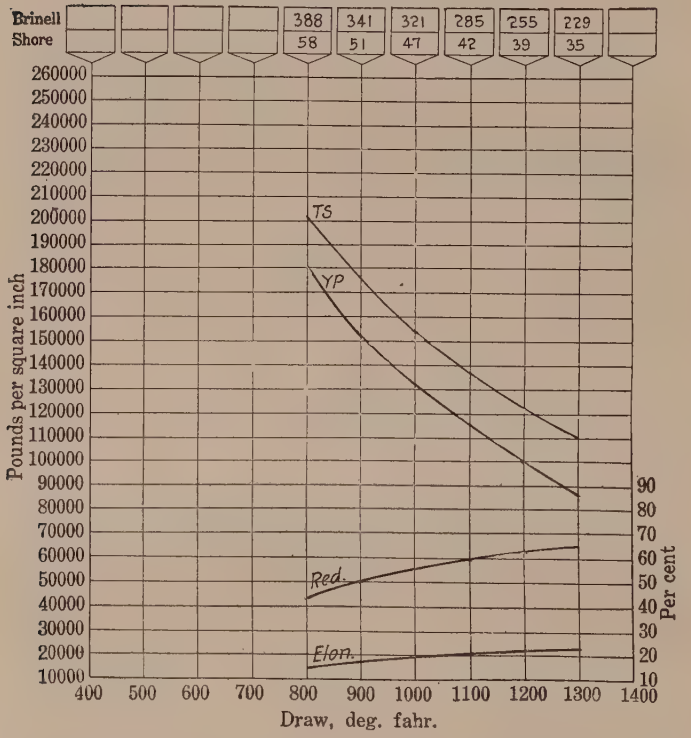
For parts that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Chart for S. A. E. Steel 3240

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.35–0.45
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

Normalized at 1625 to 1725° F.
Quenched at 1475 to 1525° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

Heat-Treatment 3240-*VIII*

(1) Normalize at 1625 to 1725° F.
(2) Reheat to 1250 to 1300° F.
(3) Cool slowly
(4) Machine
(5) Reheat to 1450 to 1500° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steels 3245 and 3250

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	3245	3250
Carbon	0.40–0.50	0.45–0.55
Manganese	0.30–0.60	0.30–0.60
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Nickel	1.50–2.00	1.50–2.00
Chromium	0.90–1.25	0.90–1.25

These steels are intended primarily for oil-hardened parts, machined or forged, that require very high physical properties. The deep penetration of the effect of heat-treatment makes them desirable steels for use in heavy sections of over 1½-in. diameter that are to be subjected to severe dynamic stresses in service.

S. A. E. Steel 3245 is specified in response to the request of the gear manufacturers, but is not recommended in the lower carbon ranges for use in gears.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3245-*VI and* 3250-*VI*

(1) Heat to 1425 to 1475° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 3245-*VII and* 3250-*VII*

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1425 to 1475° F.
(3) Quench in oil
(4) Draw to required hardness

For parts, such as gears, that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 3245-*VIII and* 3250-*VIII*

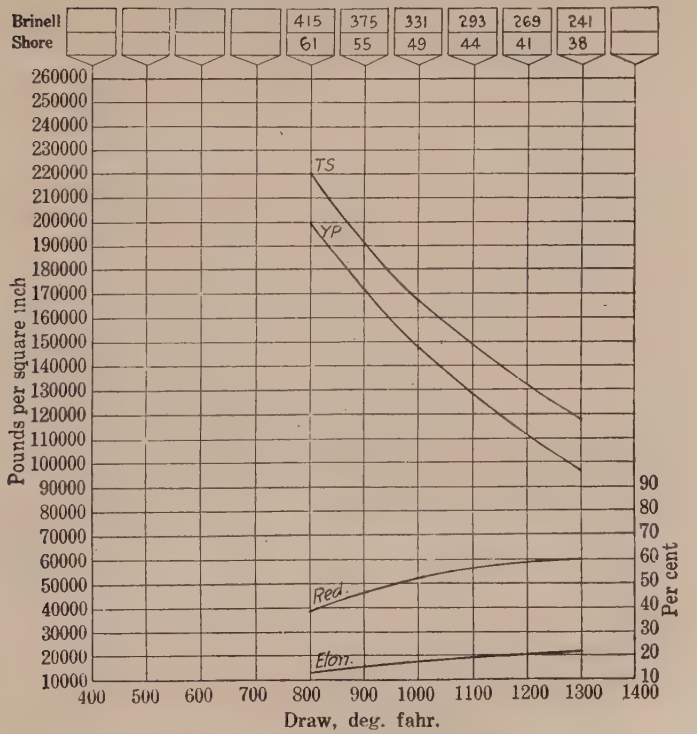
(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1250 to 1300° F.
(3) Cool slowly
(4) Machine
(5) Reheat to 1400 to 1450° F.
(6) Quench in oil
(7) Draw to required hardness

Chart for S. A. E. Steel 3250

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.45–0.55
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	1.50–2.00
Chromium	0.90–1.25

Normalized at 1600 to 1700° F.
Quenched at 1425 to 1475° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to* 1½*-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½*-in. diameter or square, this chart does not apply.*

S. A. E. Steel 3312

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.17 max.
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	3.25–3.75
Chromium	1.25–1.75

This steel is intended primarily for case-hardening when a core possessing very high strength and toughness is desired.

Carburized parts made from this steel may be subjected to Heat-Treatment II when hardness only is required and distortion is not important. When maximum hardness of the case and refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the core and the least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core is desired, distortion not being important, Heat-Treatment V should be used.

Heat-Treatment 3312-II

(1) Carburize at temperature from 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1375 to 1425° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3312-*III*

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1475 to 1525° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 3312-*IV*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1400 to 1450° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3312-*V*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1525 to 1575° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

When this steel is used for gears for which a high degree of accuracy and strength is required, it is recommended that the carburizing operation be preceded by a normalizing treatment or a quench and draw operation, which will improve the structure and machineability and tend to reduce the distortion caused by subsequent treatments.

S. A. E. Steel 3325

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels

and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.20–0.30
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	3.25–3.75
Chromium	1.25–1.75

This steel can be used interchangeably with Steel 3230 for heat-treated, machined and forged parts that must possess very high physical properties and be capable of resisting severe dynamic stresses in service.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 3325-VI

(1) Heat to 1475 to 1525° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 3325-VII

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1475 to 1525° F.
(3) Quench in oil
(4) Draw to required hardness

For parts that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 3325-VIII

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1200 to 1250° F.
(3) Cool slowly in furnace
(4) Machine
(5) Reheat to 1475 to 1525° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steels 3335 and 3340

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

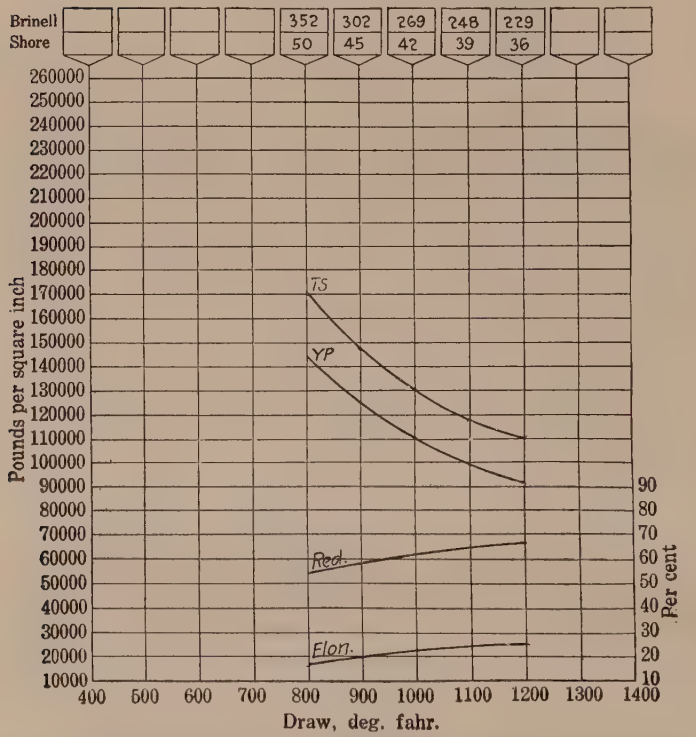
Steels	3335	3340
Carbon	0.30–0.40	0.30–0.45
Manganese	0.30–0.60	0.30–0.60
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Nickel	3.25–3.75	3.25–3.75
Chromium	1.25–1.75	1.25–1.75

Chart for S. A. E. Steel 3325

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.20–0.30
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	3.25–3.75
Chromium	1.25–1.75

Normalized at 1600 to 1700° F.
Quenched at 1475 to 1525° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

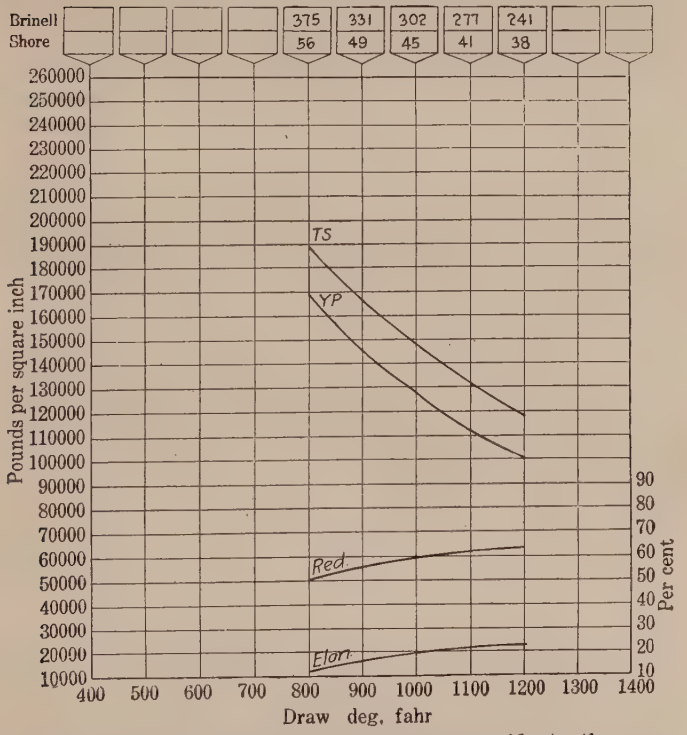
For bars over 1½-in. diameter or square, this chart does not apply.

Chart for S. A. E. Steel 3335

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.30–0.40
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	3.25–3.75
Chromium	1.25–1.75

Normalized at 1600 to 1700° F.
Quenched at 1425 to 1475° F. in *oil.*



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to* 1½*-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½*-in. diameter or square, this chart does not apply.*

These steels may be used interchangeably with Steel 3240 for such heat-treated parts, either machined or forged, as require exceptionally high physical properties and must be capable of resisting severe dynamic stresses in service.

By reason of the high alloy content of these steels and their sensitiveness to heat-treatment, it is desirable to precede all heat-treatment operations by a normalizing treatment, as recommended in Heat-Treatment VII.

Heat-Treatment 3335-*VII and* 3340-*VII*

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1425 to 1475° F.
(3) Quench in oil
(4) Draw to required hardness

For parts, such as gears, that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 3335-*VIII and* 3340-*VIII*

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1200 to 1250° F.
(3) Cool slowly in furnace
(4) Machine
(5) Reheat to 1425 to 1475° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 3415

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.10–0.20
Manganese	0.45–0.75
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	2.75–3.25
Chromium	0.60–0.95

This steel is intended primarily for case-hardening when a core possessing very high strength and toughness is desired.

When this steel is used for gears for which a high degree of accuracy and strength is required, it is recommended that the carburizing operation be preceded by a normalizing or a quench and draw operation, which will improve the structure and machineability and tend to reduce the distortion caused by subsequent treatments.

Case-hardened parts made from this steel may be subjected to Heat-Treatment II when the maximum hardness only is required and distortion is not important. When maximum hardness of the case and maximum refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the case and least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core are desired, distortion not being important, Heat-Treatment V should be used.

Heat-Treatment 3415-*II*

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1375 to 1425° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3415-*III*

(1) Carburize at 1600 to 1650° F.
(2) Quench from box in oil
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 3415-*IV*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1400 to 1450° F.
(4) Quench in oil
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 3415-*V*

(1) Carburize at 1600 to 1650° F.
(2) Cool in box
(3) Reheat to 1500 to 1550° F.
(4) Quench in oil
(5) Reheat to 1375 to 1425° F.
(6) Quench in oil
(7) Draw at 250 to 500° F. is recommended

S. A. E. Steel 3435

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.30–0.40
Manganese	0.45–0.75
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	2.75–3.25
Chromium	0.60–0.95

This steel is intended for heat-treated, machined and forged parts that are to be subjected to severe service conditions requiring higher physical properties than are obtainable with Steels 2330, 2335, 3125 or 3130. It also responds to heat-treatment more sharply and uniformly in large sections of over 1½-in. diameter than the steels mentioned.

By reason of the high alloy content of this steel and its sensitiveness to heat-treatment, it is desirable to precede all heat-treatment operations by a normalizing treatment as recommended in Heat-Treatment VII.

Heat-Treatment 3435-*VII*

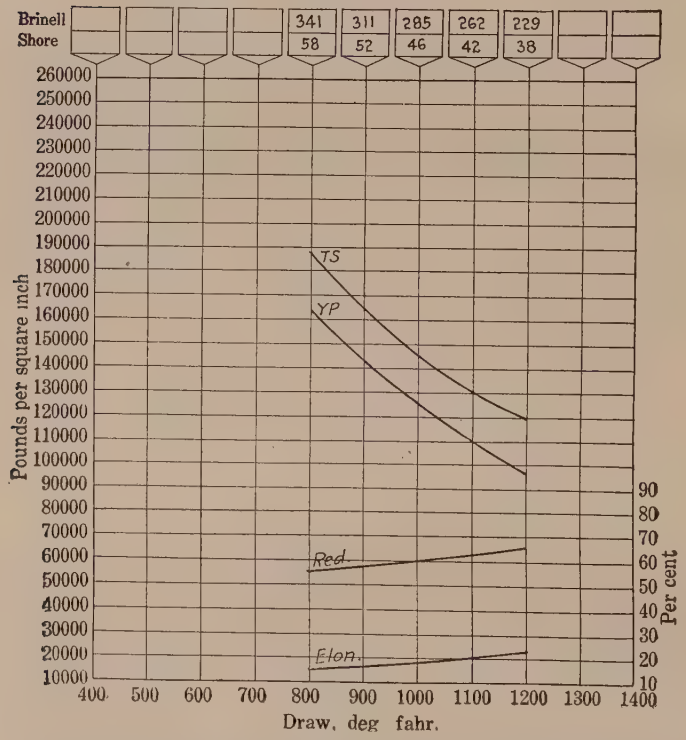
(1) Normalize at 1550 to 1650° F.
(2) Heat to 1425 to 1475° F.
(3) Quench in oil
(4) Draw to required hardness

Chart for S. A. E. Steel 3435

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.30–0.40
Manganese	0.45–0.75
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	2.75–3.75
Chromium	0.60–0.95

Normalized at 1550 to 1650° F.
Quenched at 1425 to 1475° F. in *oil*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

For parts that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 3435-*VIII*

(1) Normalize at 1550 to 1650° F
(2) Heat to 1250 to 1300° F.
(3) Cool slowly in furnace
(4) Machine
(5) Heat to 1425 to 1475° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 3450

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.45–0.55
Manganese	0.45–0.75
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	2.75–3.25
Chromium	0.60–0.95

This steel may be used interchangeably with Steels 3240 and 3340 for such heat-treated parts, either machined or forged, as require exceptionally high physical properties and must be capable of resisting severe dynamic stresses in service.

By reason of the high alloy content of this steel and its sensitiveness to heat-treatment, it is desirable to precede

all heat-treatment operations by a normalizing treatment, as recommended in Heat-Treatment VII.

Heat-Treatment 3450-*VII*

(1) Normalize at 1550 to 1650° F.
(2) Reheat to 1400 to 1450° F.
(3) Quench in oil
(4) Draw to required hardness

For parts, such as gears, that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 3450-*VIII*

(1) Normalize at 1550 to 1650° F.
(2) Reheat to 1250 to 1300° F.
(3) Cool slowly in furnace
(4) Machine
(5) Reheat to 1400 to 1450° F.
(6) Quench in oil
(7) Draw to required hardness

CHROMIUM STEELS

S. A. E. Steel 5120

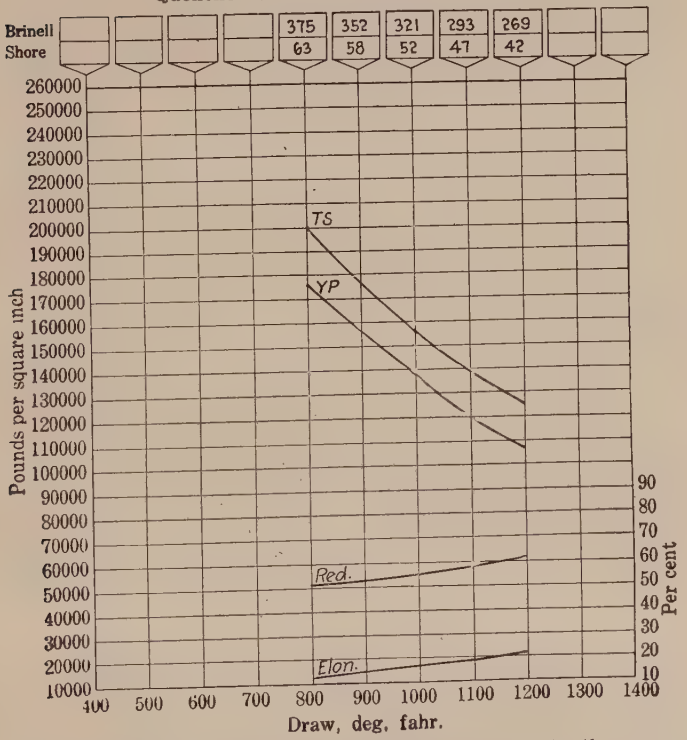
These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

Chart for S. A. E. Steel 3450

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.45–0.55
Manganese	0.45–0.75
Phosphorus	0.04 max.
Sulphur	0.04 max.
Nickel	2.75–3.25
Chromium	0.60–0.95

Normalized at 1550 to 1650° F.
Quenched at 1400 to 1450° F. in *oil*.



The accompanying chart is intended as a guide to the proper heat-treatment of this steel and to the physical properties that may be expected of a standard 0.505 x 2-in. test-specimen machined from rolled bars *up to 1½-in. diameter or square.*

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars.

For bars over 1½-in. diameter or square, this chart does not apply.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.30–0.60
Phosphorus	0.04 max.
Sulphur	0.045 max.
Chromium	0.60–0.90

Heat-Treatment 5120-*II*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box in oil
(3) Reheat to 1425 to 1475° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 5120-*III*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box in oil
(3) Reheat to 1600 to 1650° F.
(4) Quench in oil
(5) Reheat to 1425 to 1475° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

Heat-Treatment 5120-*IV*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1525 to 1575° F.
(4) Quench
(5) Draw at 250 to 500° F. is recommended

Heat-Treatment 5120-*V*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1600 to 1650° F.
(4) Quench in oil

(5) Reheat to 1425 to 1475° F.
(6) Quench
(7) Draw at 250 to 500° F. is recommended

This steel is intended primarily for case-hardening.

For structural purposes the chromium-content of this steel gives a deeper penetration of the effect of heat-treatment than can be attained in a plain carbon steel having a similar carbon content, and the physical properties are similar to those of Steels 2320 and 3120.

When this steel is to be case-hardened for use in gears for which a high degree of accuracy and strength is required, it is recommended that the carburizing operation be preceded by normalizing at 1600 to 1700° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

Case-hardened parts made from this steel may be subjected to Heat-Treatment II when maximum hardness of the case only is required and distortion is not important. When maximum hardness and maximum refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the case and the least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core is desired, distortion not being important, Heat-Treatment V should be used.

S. A. E. Steel 5140

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.35–0.45
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Chromium	0.80–1.10

This steel may be used interchangeably with Steels 2340 and 3140 for heat-treated automotive forgings requiring greater strength and toughness than are obtainable in plain carbon steels. It also has a wider heat-treating range.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 5140-*VI*

(1) Heat to 1500 to 1600° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 5140-*VII*

(1) Normalize at 1625 to 1725° F.
(2) Reheat to 1500 to 1600° F.
(3) Quench in oil
(4) Draw to required hardness

For parts that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

With regard to parts that are to be machined in automatics the temperature for Operation 2 should not exceed 1290° F., although for parts that are to be machined in lathes, the temperature may range as high as 1400° F.

Heat-Treatment 5140-*VIII*

(1) Normalize at 1625 to 1725° F.
(2) Reheat to 1250 to 1350° F.

(3) Cool slowly in furnace
(4) Machine
(5) Reheat to 1500 to 1600° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 5150

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.45–0.55
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.045 max.
Chromium	0.80–1.10

This is an oil-hardening type of steel intended for heat-treated automotive forgings that require greater strength and toughness than are obtainable with plain carbon steels or with some of the simple alloy steels having a lower carbon content. It also has a wider heat-treating range than the other simple alloy steels.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 5150-*VI*

(1) Heat to 1450 to 1550° F.
(2) Quench in oil

(3) Draw to required hardness

Heat-Treatment 5150-*VII*

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1450 to 1500° F.
(3) Quench in oil
(4) Draw to required hardness

For parts that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

With regard to parts that are to be machined in automatics the temperature for Operation 2 should not exceed 1290° F., although for parts that are to be machined in lathes, the temperature may range as high as 1400° F.

Heat-Treatment 5150-*VIII*

(1) Normalize at 1600 to 1700° F.
(2) Reheat to 1250 to 1350° F.
(3) Cool slowly in furnace
(4) Machine
(5) Reheat to 1450 to 1550° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 52100

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.95–1.10
Manganese	0.20–0.50
Phosphorus	0.03 max.
Sulphur	0.03 max.
Chromium	1.20–1.50

This steel is used chiefly for the races and balls or rollers of anti-friction bearings.

The chromium and carbon contents cause a maximum penetration of the effect of heat-treatment and develop a high degree of hardness.

For all general applications when a normalized and annealed material is to be handled, Heat-Treatment VI is recommended.

Heat-Treatment 52100-*VI*

(1) Heat to 1500 to 1550° F.
(2) Quench in oil
(3) Draw to required hardness

When the user forges or hot-presses parts to shape, a special treatment must precede all machining operations.

Heat-Treatment 52100 *Special*

(1) Heat to 1650 to 1750° F.
(2) Cool to 1000° F., black heat, by opening furnace
(3) Reheat to 1300 to 1350° F., and hold for at least thirty-six hours, or until the desired structure and machineability are obtained. Then cool slowly in furnace
(4) Machine
(5) Reheat to 1500 to 1550° F.
(6) Quench in oil
(7) Draw to required hardness

CHROMIUM-VANADIUM STEELS

S. A. E. Steels 6120

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.15–0.25
Manganese	0.50–0.80
Phosphorus	0.04 max.
Sulphur	0.04 max.
Chromium	0.80–1.10
Vanadium	0.15 min.
	0.18 desired

This steel is intended primarily for case-hardening and can be used interchangeably with Steels 2315, 2320, 3115 and 3120 for such purpose. It can also be used for structural parts after suitable heat-treatment.

Carburized parts made from this steel may be subjected to Heat-Treatment II when hardness only is required and distortion is not important. When maximum hardness of the case and maximum refinement of both the case and the core are desired, distortion again being unimportant, Heat-Treatment III should be used. When hardness, refinement of the case and the least possible distortion are required, Heat-Treatment IV should be used. When refinement of both the case and the core is desired, distortion not being important, Heat-Treatment V should be used.

When this steel is used for gears for which a high degree of accuracy and strength is required, it is recommended that the carburizing operation be preceded by normalizing at 1650 to 1750° F., which will improve the structure and tend to reduce the distortion caused by subsequent treatments.

Heat-Treatment 6120-*II*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box in oil
(3) Reheat to 1425 to 1475° F.
(4) Quench
(5) Draw to 250 to 500° F. is recommended

Heat-Treatment 6120-*III*

(1) Carburize at 1650 to 1700° F.
(2) Quench from box in oil
(3) Reheat to 1600 to 1650° F.
(4) Quench in oil
(5) Reheat to 1425 to 1475° F.
(6) Quench
(7) Draw to 250 to 500° F. is recommended

Heat-Treatment 6120-*IV*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1525 to 1575° F.
(4) Quench
(5) Draw to 250 to 500° F. is recommended

Heat-Treatment 6120-*V*

(1) Carburize at 1650 to 1700° F.
(2) Cool in box
(3) Reheat to 1600 to 1650° F.
(4) Quench in oil
(5) Reheat to 1425 to 1475° F.
(6) Quench
(7) Draw to 250 to 500° F. is recommended

S. A. E. Steels 6125 and 6130

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	6125	6130
Carbon	0.20–0.30	0.25–0.35
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Chromium	0.80–1.10	0.80–1.10
Vanadium	0.15 min.	0.15 min.
	0.18 desired	0.18 desired

This steel can be used interchangeably with Steels 2330, 2335, 3125, 3130 and 3325 for heat-treated automotive forgings requiring greater strength and toughness than are obtainable with plain carbon steel.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 6125-*VI and* 6130-*VI*

(1) Heat to 1575 to 1675° F.
(2) Quench
(3) Draw to required hardness

Heat-Treatment 6125-*VII and* 6130-*VII*

(1) Normalize at 1650 to 1750° F.
(2) Reheat to 1575 to 1675° F.
(3) Quench
(4) Draw to required hardness

For forgings that are to be machined after heat-treating, Heat-Treatment VII is recommended.

S. A. E. Steels 6135 and 6140

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They

are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	6135	6140
Carbon	0.30–0.40	0.35–0.45
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Chromium	0.80–1.10	0.80–1.10
Vanadium	0.15 min.	0.15 min.
	0.18 desired	0.19 desired

These steels can be used interchangeably with the nickel and nickel-chromium steels of similar carbon content for heat-treated automotive forgings requiring greater strength, toughness and resistance to fatiguing conditions than it is possible to obtain with plain carbon steel.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 6135-*VI and* 6140-*VI*

(1) Heat to 1550 to 1650° F.
(2) Quench in oil
(3) Draw to required hardness

For all general requirements Heat-Treatment VII is recommended.

Heat-Treatment 6135-*VII and* 6140-*VII*

(1) Normalize at 1650 to 1750° F.
(2) Reheat to 1550 to 1650° F.
(3) Quench in oil
(4) Draw to required hardness

For parts that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 6135-*VIII and* 6140-*VIII*

(1) Normalize at 1650 to 1750° F.
(2) Reheat to 1250 to 1350° F.
(3) Cool slowly
(4) Machine
(5) Reheat to 1550 to 1650° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steels 6145 and 6150

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

These steels are intended for heat-treated forgings and machined parts that are to be subjected to service conditions requiring greater strength than is obtainable with Steels 1045 and 2345 or lower chromium-nickel steels of similar carbon content.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	6145	6150
Carbon	0.40–0.50	0.45–0.55
Manganese	0.50–0.80	0.50–0.80
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Chromium	0.80–1.10	0.80–1.10
Vanadium	0.15 min.	0.15 min.
	0.18 desired	0.18 desired

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 6145-*VI and* 6150-*VI*

(1) Heat to 1525 to 1625° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 6145-*VII and* 6150-*VII*

(1) Normalize at 1650 to 1750° F.
(2) Reheat to 1525 to 1625° F.
(3) Quench in oil
(4) Draw to required hardness

For parts, such as gears, that are to be machined after forging and before treatment, Heat-Treatment VIII is recommended.

Heat-Treatment 6145-*VIII and* 6150-*VIII*

(1) Normalize at 1650 to 1750° F.
(2) Reheat to 1250 to 1350° F.
(3) Cool slowly
(4) Machine
(5) Reheat to 1525 to 1625° F.
(6) Quench in oil
(7) Draw to required hardness

S. A. E. Steel 6195

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be in-

corporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Carbon	0.90–1.05
Manganese	0.20–0.45
Phosphorus	0.03 max.
Sulphur	0.03 max.
Chromium	0.80–1.10
Vanadium	0.15 min.
	0.18 desired

This steel has a limited application in automotive construction. It has some application in anti-friction bearings and is used extensively for machine-tool parts, being primarily a tool steel.

For all general applications when a normalized and annealed material is to be handled, Heat-Treatment VI is recommended.

When the user forges or hot-presses parts to shape, a special treatment must precede all machine operations.

Heat-Treatment 6195-*VI*

(1) Heat to 1500 to 1550° F.
(2) Quench in oil
(3) Draw to required hardness

Heat-Treatment 6195 *Special*

(1) Heat to 1650 to 1750° F.
(2) Cool to 1000° F., black heat, by opening furnace
(3) Reheat to 1300 to 1350° F., and hold for at least thirty-six hours or until the desired structure and machineability are obtained. Then cool slowly in furnace
(4) Machine
(5) Reheat to 1500 to 1550° F.
(6) Quench in oil
(7) Draw to required hardness

SILICO-MANGANESE STEELS

S. A. E. Steels 9250 and 9260

These notes are not to be considered in any way a part of the standard specifications for S. A. E. Steels. They are added solely for the information of users of the steels and the guidance of purchasers in the selection of proper materials for different purposes. They should not be incorporated in the customer's specifications when ordering steel.

CHEMICAL COMPOSITION IN PERCENTAGE

Steel	9250	9260
Carbon	0.45–0.55	0.55–0.65
Manganese	0.60–0.90	0.60–0.90
Phosphorus	0.045 max.	0.045 max.
Sulphur	0.045 max.	0.045 max.
Silicon	1.80–2.20	1.80–2.20

These steels have been standardized by usage principally as spring steels. They are also used to some extent for gears with Heat-Treatment VIII. Neither steel is suitable for use without heat-treatment.

As the structure of forgings is less uniform than that of bar stock in most cases, either in the individual piece or between different pieces, normalizing as in Heat-Treatment VIII is recommended as the preliminary treatment for all forgings, but the desired physical properties of bar stock can be obtained generally without normalizing, as in Heat-Treatment VI.

Heat-Treatment 9250-VI and 9260-VI

(1) Heat to 1500 to 1650° F.
(2) Quench in oil
(3) Draw to required hardness or tests

For gears made of this steel, Heat-Treatment VIII is recommended.

Heat-Treatment 9250-VIII and 9260-VIII

(1) Normalize at 1650 to 1750° F.
(2) Reheat to 1400 to 1450° F.

(3) Cool slowly
(4) Machine
(5) Reheat to 1600 to 1650° F.
(6) Quench in oil
(7) Draw to required hardness or tests

STEEL BANDS AND STRIPS

S. A. E. STANDARD

Width Varying by $\frac{1}{16}$ Inch		Thickness, B. W. G. No.	
From	To	From	To
	$\frac{3}{8}$	4 (0.238)	18 (0.049)
	$\frac{7}{16}$	4 (0.238)	19 (0.042)
$\frac{1}{2}$	1	4 (0.238)	23 (0.025)
$1\frac{1}{16}$	2	4 (0.238)	22 (0.028)
$2\frac{1}{16}$	3	1 (0.300)	21 (0.032)
$3\frac{1}{16}$	4	1 (0.300)	20 (0.035)
$4\frac{1}{16}$	$4\frac{1}{2}$	1 (0.300)	19 (0.042)
$4\frac{9}{16}$	$4\frac{3}{4}$	00 (0.380)	18 (0.049)
$4\frac{13}{16}$	$5\frac{1}{16}$	00 (0.380)	17 (0.058)
$5\frac{1}{8}$	$6\frac{3}{4}$	00 (0.380)	16 (0.065)
	7	1 (0.300)	14 (0.083)
	$7\frac{1}{2}$	1 (0.300)	14 (0.083)
	$7\frac{5}{8}$	1 (0.300)	14 (0.083)
	$7\frac{3}{4}$	1 (0.300)	14 (0.083)
	$7\frac{7}{8}$	1 (0.300)	14 (0.083)
	8	1 (0.300)	14 (0.083)
	$8\frac{1}{4}$	1 (0.300)	14 (0.083)
	$8\frac{1}{2}$	1 (0.300)	14 (0.083)
	$8\frac{5}{8}$	1 (0.300)	14 (0.083)
	$9\frac{5}{8}$	1 (0.300)	12 (0.109)

Dimensions in inches.

The Birmingham wire gage is used by the manufacturers of steel bands, hoops and strips. The thickness desired, however, should be expressed in thousandths of an inch when writing specifications for bands, hoops or strips.

COLD-DRAWN SEAMLESS STEEL TUBING

S. A. E. STANDARD

COLD-DRAWN SEAMLESS STEEL TUBING DIMENSIONS

Thickness, B. W. G. & Fractions	Outside Diameters, In.																					
	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1¾	2	2¼	2½	2¾	3	3¼	3½					
20 (0.035)	*	*	*	*	*	*	*	*	*													
18 (0.049)	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*					
16 (0.065)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
13 (0.095)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
11 (0.120)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
10 (0.134)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
5/32 (0.156)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
3/16 (0.188)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
1/4 (0.250)					*	*	*	*	*	*	*	*	*	*	*	*	*					
5/16 (0.313)							*	*	*	*	*	*	*	*	*	*	*					
3/8 (0.375)							*	*	*	*	*	*	*	*	*	*	*					
1/2 (0.500)										*	*	*	*	*		*	*					
5/8 (0.625)																						

Inside and outside diameter tolerances: from ½ to 1¼-in. outside diameters, plus or minus 0.005 in.; from 2-in. to 3½-in. outside diameters, plus or minus 0.010 in.

Standard sizes are indicated by asterisks.

NON-FERROUS METAL SPECIFICATIONS

S. A. E. STANDARD

SOLDER

SPECIFICATION No. 1[1]

Composition in percentage:

	Class A	Class B
Tin	49.50 to 50.50	48.76 to 49.74
Lead, approx.	50.00	50.00
Antimony, max.	0.12	0.75
Copper, max.	0.08	0.15
Zinc and Aluminum	None	None
Other Impurities, max.	0.10	0.10

General Information.—The choice of the class and grade of solder for any specified purpose depends on the material in connection with which it is to be used and the method of applying. For galvanized iron and zinc, only Class A should be used. Class A solder should be furnished under this specification unless otherwise specified.

It is recommended that the grade of solder metal be selected that contains the least amount of tin required to give suitable flowing and adhesive qualities for the work in hand.

	Melting Point		Complete Liquation Point	
	Deg.Cent.	Deg.Fahr.	Deg.Cent.	Deg.Fahr.
Class A	181.0	357.8	213.0	415.4
Class B	185.0	365.0	208.0	397.4

SPECIFICATION No. 2[1]

Composition in percentage:

	Class A	Class B
Tin	44.55 to 45.45	43.07 to 43.93
Lead, approx.	55.00	55.00
Antimony, max.	0.12	1.50
Copper, max.	0.08	0.15
Zinc and Aluminum	None	None
Other Impurities, max.	0.10	0.10

[1] These specifications practically conform with Specification No. B32-21 of the American Society for Testing Materials.

General Information.—The choice of the class and grade of solder for any specified purpose depends on the material in connection with which it is to be used and the method of applying. For galvanized iron and zinc, only Class A should be used. Class A solder should be furnished under this specification unless otherwise specified.

It is recommended that the grade of solder metal be selected that contains the least amount of tin required to give suitable flowing and adhesive qualities for the work in hand.

	Melting Point		Complete Liquation Point	
	Deg.Cent.	Deg.Fahr.	Deg.Cent.	Deg.Fahr.
Class A	181	357.8	225	437.0
Class B	188	370.4	220	428.0

SPECIFICATION No. 3[1]

Composition in percentage:

	Class A	Class B
Tin	39.60 to 40.40	37.62 to 38.38
Lead, approx.	60.00	60.00
Antimony, max.	0.12	2.00
Copper, max.	0.08	0.15
Zinc and Aluminum	None	None
Other Impurities, max.	0.10	0.10

General Information.—The choice of the class and grade of solder for any specified purpose depends on the material in connection with which it is to be used and the method of applying. For galvanized iron and zinc, only Class A should be used. Class A solder should be furnished under this specification unless otherwise specified.

It is recommended that the grade of solder metal be selected that contains the least amount of tin required to give suitable flowing and adhesive qualities for the work in hand.

[1] These specifications practically conform with Specification No. B32-21 of the American Society for Testing Materials.

	Melting Point		Complete Liquation Point	
	Deg.Cent.	Deg.Fahr.	Deg.Cent.	Deg.Fahr.
Class A	181	357.8	237	458.6
Class B	188	370.4	228	442.4

SPECIFICATION No. 4

Composition in percentage:

	Class A	Class B
Tin	24.50 to 25.50	22.50 to 23.50
Lead, approx.	75.00	75.00
Antimony, max.	0.12	2.00
Copper, max.	0.08	0.15
Zinc and Aluminum	None	None
Other Impurities, max.	0.10	0.10

General Information.—This solder is recommended for use on work that is to be coated with enamel and then baked as it will withstand higher baking temperatures than solders containing larger amounts of tin.

The choice of the class and grade of solder for any specified purpose depends on the material in connection with which it is to be used and the method of applying. For galvanized iron and zinc, only Class A should be used. Class A solder should be furnished under this specimen unless otherwise specified.

It is recommended that the grade of solder metal be selected that contains the least amount of tin required to give suitable flowing and adhesive qualities for the work in hand.

	Melting Point		Complete Liquation Point	
	Deg.Cent.	Deg.Fahr.	Deg.Cent.	Deg.Fahr.
Class A	181	357.8	268	514.5
Class B	188	370.4	258	496.5

WHITE BEARING METALS

Specification No. 10, Babbitt

Composition in percentage:

Tin	90.00 to 92.00
Copper	4.00 to 5.00
Antimony	4.00 to 5.00
Lead, max.	0.35
Iron, max.	0.08
Arsenic, max.	0.10
Bismuth, max.	0.08
Zinc and Aluminum	None

This analysis applies to the metal in the ingot form. When finished bearings are purchased a maximum of 0.6% lead is permissible in scraped samples provided a lead-tin solder has been used in bonding the bronze and the babbitt.

General Information.—This babbitt is very fluid and may be used for bronze-backed bearings, particularly for thin linings such as are used in aircraft engines. It is also suitable for die castings.

Specification No. 11, Babbitt

Composition in percentage:

Tin	86.00 to 89.00
Copper	5.00 to 6.50
Antimony	6.00 to 7.50
Lead, max.	0.35
Iron, max.	0.08
Arsenic, max.	0.10
Bismuth, max.	0.08
Zinc and Aluminum	None

General Information.—This is a rather hard babbitt which may be used for lining connection-rod and shaft bearings which are subjected to heavy pressures; its "wiping" tendency is very slight. It is also suitable for die castings.

Specification No. 12, Babbitt

Composition in percentage:

Antimony	9.50 to 11.50
Copper	2.25 to 3.75
Lead	24.00 to 26.00
Iron, max.	0.08
Bismuth, max.	0.08
Zinc and Aluminum	None
Tin	Remainder

General Information.—This is a relatively cheap babbitt and is intended for bearings subjected to moderate pressures. It is also suitable for die castings.

Specification No. 13, Babbitt

Composition in percentage:

Tin	4.50 to 5.50
Antimony	9.25 to 10.75
Copper, max.	0.50
Lead	84.00 to 86.00
Arsenic, max.	0.20
Zinc and Aluminum	None

General Information.—This is a cheap babbitt and serves successfully where the bearings are large and the service light. It should not be used as a substitute for a babbitt with a high tin content. It is also suitable for die castings.

Specification No. 14, Babbitt

Composition in percentage:

Tin	9.25 to 10.75
Antimony	14.00 to 16.00
Lead	74.00 to 76.00
Copper, max.	0.50
Arsenic, max.	0.20
Zinc and Aluminum	None

General Information.—This is a cheap babbitt and serves successfully where the bearings are large and the service light. It should not be used as a substitute for a babbitt with a high tin content. It is also suitable for die castings.

ALUMINUM ALLOYS

Specification No. 30

Composition in percentage:

Aluminum	90.00
Copper	7.00 to 8.50
Zinc, max.	0.20
Silicon, Iron, Zinc, Manganese and Tin, max.	1.70
Other Impurities	None

General Information.—The tensile strength of test-specimens about ½ in. diameter of this alloy cast in sand and tested without machining off the skin should be about 18,000 to 20,000 lb. per sq. in., and the elongation 1 to 2 per cent. in 2 in.

This is a light alloy having a specific gravity of about 2.83 and is used more extensively in the automotive industry than all other light casting alloys combined. A shrinkage of 0.156 (5/32) in. per ft. should be allowed in pattern designs. This alloy is used for crankcases, oil-pans, steering-wheel spiders, differential carriers, transmission cases, camshaft housings, hub-caps and similar parts.

Specification No. 31

Composition in percentage:

Aluminum, min.	81.00
Copper	2.25 to 3.25
Zinc	12.50 to 14.50
Silicon, Iron, Manganese and Tin, max.	1.70
Other Impurities	None

General Information.—The tensile strength of test-specimens about ½ in. diameter of this alloy cast in sand and tested without machining off the skin should be about 25,000 to 30,000 lb. per sq. in. with an elongation of more than 1 per cent in 2 in.

The specific gravity is about 3.0 and a shrinkage of

0.156 (5/32) in. per ft. should be allowed in pattern designs.

This alloy is used extensively in England for such parts as crank cases, oil-pans, steering-wheel spiders and transmission cases.

SPECIFICATION No. 32

Composition in percentage:

Aluminum, min.	85.50
Copper	11.00 to 13.50
Zinc, max.	0.20
Silicon, Iron, Zinc, Manganese and Tin, max.	1.70
Other Impurities	None

General Information.—The tensile strength of test-specimens about ½ in. diameter of this alloy cast in sand and tested without machining off the skin should be about 19,000 to 23,000 lb. per sq. in. and the elongation will be practically nothing.

The specific gravity of this alloy is about 2.95 and a shrinkage of 0.156 (5/32) in. per ft. should be allowed in pattern designs. This alloy is used for manifolds, pumps, carbureters, cylinders and other parts which should be free from leaks and where the brittleness of the alloy is not objectionable.

SPECIFICATION No. 33

Composition in percentage:

Aluminum	88.00 to 92.00
Copper	6.00 to 8.00
Zinc, max.	2.50
Iron, max.	1.50
Silicon, Manganese and Tin, max.	0.75
Other Impurities	None

General Information.—The tensile strength of test-specimens about ½ in. diameter of this alloy cast in sand and tested without machining off the skin should be about

19,000 to 21,000 lb. per sq. in. with an elongation of 1 to 2 per cent in 2 in.

This is a light alloy having a specific gravity of 2.83 to 2.86 and is used extensively in the automotive industry. A shrinkage of 0.156 (5/32) in. per ft. should be allowed in pattern designs.

This alloy is similar to Specification No. 30 and is used for crank cases, oil-pans, steering-wheel spiders, differential carriers, transmission cases, camshaft housings, hub-caps and similar parts.

CAST BRASS ALLOYS

Specification No. 40, Red Brass

Composition in percentage:

Copper	83.00 to 86.00
Tin	4.50 to 5.50
Lead	4.50 to 5.50
Zinc	4.50 to 5.50
Iron, max.	0.35
Antimony, max.	0.25
Aluminum	None

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	27,000
Yield point, lb. per sq. in.	12,000
Elongation in 2 in. or proportionate gage length, per cent	16

This is a free-cutting brass with good casting and finishing properties.

Specification No. 41, Yellow Brass

Composition in percentage:

Copper	62.00 to 65.00
Lead	2.00 to 4.00
Zinc	31.00 to 36.00
Tin, max.	1.00

Iron, max.	0.50
Aluminum	None
Other Impurities	0.25

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	25,000
Yield point, lb. per sq. in.	12,000
Elongation in 2 in. or proportionate gage length, per cent	20

This alloy is intended for use in commercial castings where cheapness and good machining properties are the main considerations.

Specification No. 42, White Nickel Brass

Composition in percentage:

Copper	55.00 to 64.00
Nickel, min.	18.00
Iron, max.	0.35
Aluminum	None
Other Impurities	0.25
Zinc	Remainder

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	30,000
Elongation in 2 in. or proportionate gage length, per cent	20

This brass is intended for use for trimmings or other parts requiring a metallic-white finish. The higher the nickel content, the more permanent will be the color.

Specification No. 43, Manganese Bronze[1]

Composition in percentage:

Copper	53.00 to 62.00

[1] This specification is substantially the same as Specification No. B7-14 of the American Society for Testing Materials.

Zinc	38.00 to 47.00
Lead, max.	0.15

This metal may be hardened by the addition of small amounts of tin, iron, manganese, aluminum or a combination of these metals. Good sand castings made of this alloy should give the following minima in physical characteristics:

Tensile-strength, lb. per sq. in.	60,000
Yield-point, lb. per sq. in.	30,000
Elongation in 2 in. or proportionate gage length, per cent	15

For the purpose of inspection, the most importance should be placed on the following minima in physical requirements on a special chill cast S. A. E. Standard test-bar. This test-bar shall be cut from one corner, near the bottom of the test ingot, cast in a properly tapered iron mold, approximately 3 in. deep by 2¾ in. wide by 12 in. long.

Tensile-strength, lb. per sq. in.	70,000
Elongation in 2 in., per cent	20

General Information.—This alloy is intended for use in castings where strength and toughness are required. It is equivalent to the copper-zinc alloys commercially known as Cast Manganese Bronze or its equivalents, such as Cast Tobin Bronze and Cast Naval Bronze.

Specification No. 44, Cast Brass to Be Brazed

Composition in percentage:

Copper	83.00 to 86.00
Zinc	14.00 to 17.00
Lead, max.	0.50
Iron, max.	0.15

General Information.—This brass starts to melt at approximately 1830° F. and is entirely melted at approximately 1870° F. As a brazing material on this brass to be brazed either Silver Solder or a brazing brass melting

at a temperature lower than the brass to be brazed should be used.

Specification No. 45, Brazing Solder

Composition in percentage:

Copper	48.00 to 52.00
Lead, max.	0.50
Iron, max.	0.10
Zinc	Remainder

General Information.—This solder starts to melt at approximately 1560° F. and is entirely melted at approximately 1600° F. It may be used by melting it in a crucible under a flux of borax, with or without the addition of boric acid, and dipping the material to be brazed in the melted brazing solder; or this brazing solder, in a powdered form, may be mixed with the flux applied to the material to be brazed, and melted either in a furnace or by the use of a brazing torch.

BRONZE ALLOYS

Bearings or gears made of bronze alloys should be used only against hardened steel.

Specification No. 62, Hard Cast Bronze

Composition in percentage:

Copper	86.00 to 89.00
Tin	9.00 to 11.00
Lead, max.	0.20
Iron, max.	0.06
Zinc	1.00 to 3.00

General Information.—Good castings made of this bronze should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	30,000
Yield point, lb. per sq. in.	15,000
Elongation in 2 in. or proportionate gage length, per cent	14

This alloy is suitable wherever a strong general utility

bronze is required. It may be be used for severe working conditions where heavy pressures obtain, as in gears and bearings.

Specification No. 63, Leaded Gun Metal

Composition in percentage:

Copper	86.00 to 89.00
Tin	9.00 to 11.00
Phosphorus, max.	0.25
Zinc and Other Impurities, max.	0.50
Lead	1.00 to 2.50

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	30,000
Yield point, lb. per sq. in.	12,000
Elongation in 2 in. or proportionate gage length, per cent	10

Combining strength with fair machining qualities, this general utility bronze is especially good for bushings subjected to heavy loads and severe working conditions.

Specification No. 64, Phosphor Bronze

Composition in percentage:

Copper	78.50 to 81.50
Tin	9.00 to 11.00
Lead	9.00 to 11.00
Phosphorus	0.05 to 0.25
Zinc, max.	0.75
Other Impurities, max.	0.25

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	25,000
Yield point, lb. per sq. in.	12,000
Elongation in 2 in. or proportionate gage length, per cent	8

This metal is an excellent composition for use where anti-friction qualities are desired, standing up exceedingly well under heavy loads and severe usage.

Specification No. 65, Phosphor Gear Bronze

Composition in percentage:

Copper	88.00 to 90.00
Tin	10.00 to 12.00
Phosphorus	0.10 to 0.30
Lead, Zinc and Other Impurities, max.	0.50

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	35,000
Yield point, lb. per sq. in.	20,000
Elongation in 2 in. or proportionate gage length, per cent	10

This is a very hard bronze and may be used for gears and worm wheels where the requirements are severe.

Specification No. 66, Bronze Backing for Lined Bearings

Composition in percentage:

Copper	83.00 to 86.00
Tin	4.50 to 6.00
Lead	8.00 to 10.00
Zinc, max.	2.00
Impurities, max.	0.25

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	25,000
Yield point, lb. per sq. in.	12,000
Elongation in 2 in. or proportionate gage length, per cent	8

This composition is recommended as an inexpensive but suitable alloy for bronze-backed bearings.

Specification No. 67, Semi-Plastic Bronze

Composition in percentage:

Copper	75.50 to 78.50
Tin	7.25 to 8.75
Lead	13.50 to 16.50
Zinc, max.	0.50
Phosphorus, max.	0.25
Iron, max.	0.25
Antimony, max.	0.50
Aluminum	None
Impurities, max.	0.75

General Information.—Good castings made of this alloy should give the following minima in physical characteristics:

Ultimate strength, lb. per sq. in.	20,000
Elongation in 2 in. or proportionate gage length, per cent	10

This metal is intended for use where a soft bronze with good anti-friction qualities is desired.

Specification No. 68, Cast Aluminum Bronze

Composition in percentage:

Copper	85.00 to 87.00
Aluminum	7.00 to 9.00
Iron	2.50 to 4.50
Tin (none desired), max.	0.50
Other Impurities, max.	0.25

General Information.—Good castings made of this alloy should give the following minima in mechanical characteristics:

Ultimate strength, lb. per sq. in.	65,000
Yield point, lb. per sq. in.	20,000
Elongation in 2 in. or proportionate gage length, per cent	20

This is a non-corrodible alloy of great strength with a hardness equal to that of manganese bronze and good bearing qualities. It is suitable for use in worm wheels, gears and similar parts.

Specification No. 69, Wrought Aluminum Bronze

Composition in percentage:

Copper	85.00 to 87.00
Aluminum	7.00 to 9.00
Iron	2.50 to 4.50
Tin (none desired), max.	0.50
Other Impurities, max.	0.25

General Information.—Wrought shapes, rods and bars of this alloy, the composition of which is identical with Specification No. 68, combine unusual strength with good bearing and anti-corrosive qualities.

Wrought bars made of this alloy, when annealed or hot-rolled, should give the following minima in physical characteristics:

Diameter or Thickness, In.		Ultimate Strength Lb. per Sq. In.	Yield Point, Lb. Per Sq. In.	Elongation in 2 In. or Proportionate Gage Length, Per Cent
Over	To and Including			
0	½	80,000	40,000	30
½	1	75,000	37,500	28
1		72,000	35,000	25

WROUGHT NON-FERROUS METAL ALLOYS

Specification No. 70, Commercial Brass Sheet

Composition in percentage:

Copper	64.50 to 67.50
Lead, max.	0.30
Iron, max.	0.05
Other Impurities, max.	0.10
Zinc	Remainder

Mechanical Requirements

Temper and Anneal.—The temper of sheet brass shall be designated as follows:

	Reduction, B. & S. Gage Nos.
Quarter Hard	1
Half Hard	2
Hard	4
Extra Hard	6
Spring	8

The annealed sheet shall be designated as follows:
Light Anneal,
Drawing Anneal,
Soft Drawing Anneal.

The average Brinell hardness of ten samples of sheet 0.080 in. or over in thickness shall be within the following limits:

Quarter Hard	75-95
Half Hard	95-115
Hard	130-150
Extra Hard	150-170
Spring	160-180
Light Anneal	65-75
Drawing Anneal	55-65
Soft Drawing Anneal	47-55

The average of tension tests of two samples of sheet thinner than 0.080 in. shall conform to the following minimum requirements:

Temper	Min. Ult. Strength, Lb. Per Sq. In.	Min. Elongation in 2 In., Per Cent
Quarter Hard	45,000	27.5
Half Hard	52,500	15.0
Hard	67,500	5.0
Extra Hard	80,000	2.0
Spring	87,500	1.0
Light Anneal	45,000	32.0
Drawing Anneal	42,000	38.0
Soft Drawing Anneal	40,000	42.0

In very thin strips, on account of the difficulties in testing, the elongation may be considerably less than the figures given above.

These should be considered as general specifications. Since high brass is used for many purposes where the requirements of the operations used are too particular to be specified by any of the ordinary physical tests, it is frequently advisable to submit samples or drawings to the manufacturer and secure an adjustment of anneal or temper to suit the actual operations to which the material is to be submitted.

THICKNESS TOLERANCES

B. & S. Gage No.		Decimal		Up to 5 in. Wide, Incl.	Over 5 in. to 8 in. Wide, Incl.	Over 8 in. to 11 in. Wide, Incl.	Over 11 in. to 14 in. Wide, Incl.
From	To, Incl.	From	To, Incl.				
0000	0	0.4600	0.3248	0.0044	0.0048	0.0051	0.0055
0	4	0.3248	0.2043	0.0039	0.0043	0.0046	0.0050
4	8	0.2043	0.1284	0.0034	0.0038	0.0041	0.0045
8	14	0.1284	0.0640	0.0029	0.0033	0.0036	0.0040
14	18	0.0640	0.0403	0.0025	0.0029	0.0033	0.0037
18	24	0.0403	0.0201	0.0020	0.0024	0.0028	0.0032
24	28	0.0201	0.0126	0.0016	0.0020	0.0024	0.0028
28	32	0.0126	0.0079	0.0013	0.0017	0.0020	0.0024
32	35	0.0079	0.0056	0.0010	0.0014	0.0017	0.0022
35	38	0.0056	0.0039	0.0008	0.0012	0.0015	0.0019

All dimensions in inches. All tolerances plus or minus.

Specification No. 71, Copper Sheet

Composition in percentage:

Copper, min. 99.50

Mechanical Requirements

TENSILE STRENGTH AND ELONGATION

Copper	Thickness, In.	Tensile-Strength, Lb. Per Sq. In.	Elongation in 2 In., Minimum, Per Cent
Soft	0.005 to 0.031	37,000 Max.	20.0
	0.032 to 0.375	36,000 Max.	25.0
Hard*	0.072 to 0.375	40,000 Min.	8.0
	over 0.375	35,000 Min.	15.0

* Hard copper less than 0.072 in. thick should be made as hard as possible and still stand cold bending through an angle of 180° flat back without fracture on the outside of the bent portion.

THICKNESS TOLERANCES

B. & S. Gage No.		Decimal		Up to 5 in. Wide, Incl.	Over 5 in. to 8 in. Wide, Incl.	Over 8 in. to 11 in. Wide, Incl.	Over 11 in. to 14 in. Wide, Incl.
From	To, Incl.	From	To, Incl.				
0000	0	0.4600	0.3248	0.0044	0.0048	0.0051	0.0055
0	4	0.3248	0.2043	0.0039	0.0043	0.0046	0.0050
4	8	0.2043	0.1284	0.0034	0.0038	0.0041	0.0045
8	14	0.1284	0.0640	0.0029	0.0033	0.0036	0.0040
14	18	0.0640	0.0403	0.0025	0.0029	0.0033	0.0037
18	24	0.0403	0.0201	0.0020	0.0024	0.0028	0.0032
24	28	0.0201	0.0126	0.0016	0.0020	0.0024	0.0028
28	32	0.0126	0.0079	0.0013	0.0017	0.0020	0.0024
32	35	0.0079	0.0056	0.0010	0.0014	0.0017	0.0022
35	38	0.0056	0.0039	0.0008	0.0012	0.0015	0.0019

These should be considered as general specifications. Since copper is used for many purposes where the requirements of the operations used are too particular to be specified by any of the ordinary physical tests, it is frequently advisable to submit samples or drawings to the manufacturer and secure an adjustment of anneal or temper to suit the actual operations to which the material is to be submitted.

Specification No. 72, Free-Cutting Brass Rod

Composition in percentage:

Copper	60.00 to 63.00
Lead	2.25 to 3.25
Iron, max.	0.15
Other Impurities, max.	0.25
Zinc	Remainder

When several bars or rods are analyzed they should meet this specification. If only one rod or bar is sampled, the following limits will be acceptable:

Copper, per cent	59.40 to 63.60
Lead, per cent	1.80 to 3.90

Mechanical Requirements

Bend Test.—Rods or bars shall bend cold without fracture through an angle of 120° around a pin the radius

of which is equal to the diameter or thickness of the rod or bar.

Dimensions and Tolerances.—The diameter of round sections shall not vary from that specified by more than the tolerances given in the following table:

Diameter, In.		Tolerances, In. Plus or Minus
Over	To and Including	
0	½	0.0015
½	1	0.0020
1	2½	0.0025
2½		0.0030

In the case of other than round sections the distance between parallel faces shall be permitted to vary, in their respective sizes, double the amount of the above tolerances.

SPECIFICATION NO. 73, NAVAL BRASS (TOBIN BRONZE) ROD

Composition in percentage:

Copper	59.00 to 62.00
Tin	0.50 to 1.50
Iron, max.	0.10
Lead, max.	0.30
Other Impurities, max.	0.10
Zinc	Remainder

MECHANICAL REQUIREMENTS

TENSILE TEST DATA

Diameter or Thickness, In.		Minimum Tensile-Strength, Lb. Per Sq. In.	Minimum Yield-Point, Lb. Per Sq. In.	Minimum Elongation in 2 In., Per Cent
Over	To and Including			
0	1	62,000	31,000	25.0
1	2½	60,000	30,000	30.0
2½	3½	56,000	25,000	35.0
3½		54,000	22,000	40.0

Strain Test.—A full-size test-specimen must stand immersion for fifteen minutes without cracking in an aqueous solution containing 100 grams of mercurous nitrate and 13 cc. of nitric acid (specific gravity 1.42) per liter.

Bend Test.—The rods shall stand cold-bending without fracture through an angle of 120° around a pin, the radius of which is equal to the diameter or thickness of the rod or bar.

Dimensions and Tolerances.—The diameter of round sections shall not vary from that specified by more than the tolerances specified in the following table:

Diameter, In.		Tolerances, In. Plus or Minus
Over	To and Including	
0	½	0.0015
½	1	0.0020
1	2½	0.0025
2½		0.0030

In case of other than round sections the distance between parallel faces shall be permitted to vary, in their respective sizes, double the amount of the above tolerances.

General Information.—This material is intended for use wherever brass rod that is stronger, tougher, and less corrodible than commercial brass rod is required.

Specification No. 74, Annealed Seamless Brass Tubing

Composition in percentage:

Copper, min.	60.00
Lead, max.	1.00
Iron, max.	0.10
Zinc	Remainder

Mechanical Requirements

Tensile Test.—Ultimate strength, min., lb. per sq. in., 40,000. Elongation in 2 in. or proportionate gage length, min., per cent, 25.

Expanding Test.—A pin having a taper of 1 to 8 shall be driven into one end of a tube until the diameter is increased 15%. The tube shall withstand this test without showing cracks, splits or other defects.

Appearance.—These tubes shall be clean, smooth and free from injurious defects, both inside and outside.

DIMENSIONAL TOLERANCES

Outside Diameter		Tolerances[1] Plus or Minus	Wall Thickness		Tolerances Plus or Minus
Over	To		Over	To	
0	1/2	0.002	0	1/64	0.001
1/2	3/4	0.0025	1/64	1/32	0.002
3/4	1	0.003	1/32	1/16	0.003
1	1 1/4	0.0035	1/16	1/8	0.005
1 1/4	1 1/2	0.004	1/8	1/4	0.008
1 1/2	1 3/4	0.0045	1/4	5/16	0.0125
1 3/4	2	0.005	5/16	3/8	0.015
2		0.0025 x diam.			

All dimensions in inches.
[1] Either inside or outside diameter.
No combination of variations on the same tube shall make the thickness of the wall vary from the nominal by more than these amounts.

Special Limits.—On all stock where the above commercial variations are not permissible, the limits shall be specified in the order.

Specification No. 75, Copper Tubing

Composition in percentage:

Copper, min. 99.50

Mechanical Requirements, Hard-Drawn Tubes

Expanding Test.—A pin having a taper of 1 to 8 shall be driven into one end of a tube until the diameter is in-

creased 15%. The tube must withstand the test without showing cracks, splits or other defects.

Bend Test.—One test-specimen cut longitudinally and one cut transversely from the tube shall be tested. Test-specimens must withstand cold-bending through an angle of 180° on a radius equal to the thickness of the wall of the tube without cracking.

MECHANICAL REQUIREMENTS, ANNEALED TUBES

Expanding Test.—A pin having a taper of 1 to 8 shall be driven into one end of a tube until the diameter is increased 15%. The tube must withstand the test without showing cracks, splits or other defects.

Bend Test.—One test-specimen cut longitudinally and one cut transversely from the tube shall be tested. Test-specimens must withstand bending through an angle of 180°, that is flat on itself, without cracking. The metal must not crack when hammered to a fine edge.

Appearance.—These tubes shall be clean, smooth and free from injurious defects, both inside and outside.

DIMENSIONAL TOLERANCES

Outside Diameter		Tolerances[1] Plus or Minus	Wall Thickness		Tolerances Plus or Minus
Over	To		Over	To	
0	1/2	0.002	0	1/64	0.001
1/2	3/4	0.0025	1/64	1/32	0.002
3/4	1	0.003	1/32	1/16	0.003
1	1 1/4	0.0035	1/16	1/8	0.005
1 1/4	1 1/2	0.004	1/8	1/4	0.008
1 1/2	1 3/4	0.0045	1/4	5/16	0.0125
1 3/4	2	0.005	5/16	3/8	0.015
2		0.0025 x diam.			

All dimensions in inches.

[1] Either inside or outside diameter.

No combination of variations on the same tube shall make the thickness of the wall vary from the nominal by more than these amounts.

Special Limits.—On all stock where the above commercial variations are not permissible limits shall be specified in the order.

SPECIFICATION No. 76, NAVAL BRASS (TOBIN BRONZE) TUBING

Composition in percentage:

Copper	59.00 to 62.00
Tin	0.50 to 1.50
Iron, max.	0.10
Lead, max.	0.30
Other Impurities, max.	1.10
Zinc	Remainder

MECHANICAL REQUIREMENTS

TENSILE-TEST DATA

Thickness of Wall, In.		Minimum Tensile-Strength, Lb. Per Sq. In.	Minimum Yield-Point, Lb. Per Sq. In.	Minimum Elongation in 2 In., Per Cent
Over	To and Including			
0	$\frac{1}{8}$	60,000	24,000	28
$\frac{1}{8}$	$\frac{1}{4}$	55,000	22,000	32
$\frac{1}{4}$		50,000	20,000	35

DIMENSIONAL TOLERANCES

Outside Diameter		Tolerances[1] Plus or Minus	Wall Thickness		Tolerances,[2] Plus or Minus
Over	To		Over	To	
$\frac{1}{2}$	$\frac{3}{4}$	0.0025	$\frac{1}{64}$	$\frac{1}{32}$	0.0020
$\frac{3}{4}$	1	0.0030	$\frac{1}{32}$	$\frac{1}{16}$	0.0030
1	$1\frac{1}{4}$	0.0035	$\frac{1}{16}$	$\frac{1}{8}$	0.0050
$1\frac{1}{4}$	$1\frac{1}{2}$	0.0040	$\frac{1}{8}$	$\frac{1}{4}$	0.0080
$1\frac{1}{2}$	$1\frac{3}{4}$	0.0045	$\frac{1}{4}$	$\frac{5}{16}$	0.0125
$1\frac{3}{4}$	2	0.0050	$\frac{5}{16}$	$\frac{3}{8}$	0.0150
2		0.0025 x diam.			

All dimensions in inches.

[1] Either inside or outside diameter.

[2] No combination of variations on the same tube shall make the thickness of the wall vary from the nominal by more than these amounts.

Expanding Test.—A pin having a taper of 1 to 8 shall be driven into one end of a tube until the diameter is increased 15%. The tube shall withstand this test without showing cracks, splits or other defects.

Appearance.—These tubes shall be clean, smooth and free from injurious defects, both inside and outside.

Special Limits.—On all stock where the above commercial variations are not permissible, the limits shall be specified in the order.

Specification No. 80, Brass Spring Wire

Composition in percentage:

	Grade A	Grade B
Copper	70.00 to 74.00	64.00 to 68.00
Lead, max.	0.10	0.10
Iron, max.	0.06	0.07
Zinc	Remainder	Remainder

Physical Properties.—This wire shall have a tensile-strength of at least 100,000 lb. per sq. in., but should be capable of being bent through an angle of 180° around a wire of the same diameter without breaking.

Appearance.—The wire shall be uniform in quality and temper, cylindrical in shape and smooth and free from injurious defects.

Grade A is for use where the requirements are especially severe. Grade B is for use under ordinary conditions, and will be furnished unless otherwise specified.

Dimensional Tolerances.—The wire shall not vary from the specified diameter by more than plus or minus 1% for sizes larger than 0.050 in.

From 0.050 to 0.025 in. the variation in size shall not be more than plus or minus 0.0005 in.

For sizes smaller than 0.025 in. the variation shall not be more than plus or minus 0.00025 in.

SPECIFICATION No. 81, PHOSPHOR BRONZE SPRING WIRE

Composition in percentage:

Tin	4.00 to 6.00
Phosphorus	0.03 to 0.40
Zinc, max.	0.20
Iron, max.	0.10
Lead, max.	0.10
Copper	Remainder

Bend Test.—The wire shall be capable of being bent through an angle of 180° flat back on itself without fracture on the outside of the bent portion.

MECHANICAL REQUIREMENTS

Wire Diameter, In.		Minimum Tensile-Strength, Lb. Per Sq. In.
Over	To and Including	
0.0000	0.0625	130,000
0.0625	0.1250	120,000
0.1250	0.2500	110,000
0.2500	0.3750	100,000

Appearance.—The wire shall be uniform in quality and temper, cylindrical in shape and smooth and free from injurious defects.

Dimensional Tolerances.—The wire shall not vary from the specified diameter by more than plus or minus 1% for sizes larger than 0.050 in.

From 0.050 to 0.025 in. the variation in size shall not be more than plus or minus 0.0005 in.

For sizes smaller than 0.025 in. the variation shall not be more than plus or minus 0.00025 in.

SPECIFICATION No. 88, BRASS FORGING ROD

Composition in percentage:

Copper	58.50 to 61.50
Lead	1.50 to 2.50

Iron, max.	0.15
Materials other than Copper, Lead and Zinc, max.	0.35
Zinc	Remainder

When the sample is taken from several bars or rods, for analysis, it should meet this specification. If only one rod or bar is sampled, the following composition in percentage will be acceptable.

Copper	57.9 to 62.1
Lead	1.2 to 3.0

Mechanical Requirements

Flattening Test.—Specimens cut from rods or bars and having a length equal to the diameter of the specimen, shall stand flattening in an axial direction while hot, until reduced to 20% of their original length, without cracking.

Dimensions and Tolerances.—The diameter of the round sections shall not vary from that specified by more than the tolerances specified in the following table:

Diameter, In.		Tolerances, In.
Over	To and Including	
0	½	±0.005
½	1	±0.008
1	2½	±0.010
2½		±0.015

General Information.—These specifications cover brass rods of any specified cross-section capable of being readily forged while hot and easily machined.

The rods may be manufactured either by hot-rolling or extrusion, and may be finished by cold-drawing if necessary to meet the requirements for size.

CHAPTER XXV

REFERENCE DATA

INCHES IN DECIMAL EQUIVALENT OF A FOOT

Inches	0	1/8″	1/4″	3/8″	1/2″	5/8″	3/4″	7/8″
0	.000	.010	.021	.031	.042	.052	.063	.073
1″	.083	.094	.104	.115	.125	.135	.146	.156
2″	.167	.177	.188	.198	.208	.219	.229	.240
3″	.250	.260	.270	.281	.292	.302	.313	.323
4″	.333	.344	.354	.364	.375	.385	.396	.406
5″	.416	.427	.437	.448	.458	.469	.479	.490
6″	.500	.510	.520	.531	.542	.552	.563	.573
7″	.583	.594	.604	.615	.625	.635	.646	.656
8″	.666	.677	.687	.698	.708	.719	.729	.740
9″	.750	.760	.770	.781	.792	.802	.813	.823
10″	.833	.844	.854	.865	.875	.885	.896	.906
11″	.916	.927	.937	.948	.958	.969	.979	.990

EXAMPLE:—To find decimal equivalent of a foot for 3 1/8 inches, look opposite 3 inches and under 1/8 in. or .260.

EXPANSION OF BODIES BY HEAT

It is often desirable to find the changes in dimensions in a body brought about by changes in its temperature. The *linear coefficient of expansion* of a body is the rate at which the unit of length changes with an increase of one degree of temperature. The following example will illustrate how the change of length can be determined when its *coefficient of expansion* and change of temperature are known.

Let "L" equal the length of the bar in inches, "T" the number of degrees change in temperature, and "N" the coefficient of expansion. The change of length is then equal to L x T x N. The new length will, of course, be equal to L, the original length, plus L x T x N, if the temperature increased, of L minus L x T x N, if the temperature decreased.

The coefficient of expansion of a number of more common substances is given in the attached table (See Table No. 1). Following is given a practical example of how it can be practically employed.

What will be the change in length of a steel girder ten feet long when the temperature changes from zero Fahrenheit to 75° Fahrenheit? In this case L = 10 feet, or 120 inches, T = 75° and, assuming the girder to be made of medium steel, the coefficient of expansion is .0000067. The change of length is, therefore, equal to 120 x 75 x .0000067, or .0603 inches.

TABLE I

COEFFICIENTS OF EXPANSION

Substance	Linear Expansion	
	Centigrade	Fahrenheit
METALS AND ALLOYS		
Aluminum, wrought	.00231	.00128
Brass	.00188	.00104
" wire	.00193	.00107
Bronze	.00181	.00101
Copper	.00168	.00093
German Silver	.00183	.00102
Gold	.00150	.00083
Iron, cast, gray	.00106	.00059
" wrought	.00120	.00067
" wire	.00124	.00069
Lead	.00286	.00159
Nickel	.00126	.00070
Platinum	.00090	.00050
Platinum—Iridium, 15% Iridium	.00081	.00045
Silver	.00192	.00107
Steel, cast	.00110	.00061
" hard	.00132	.00073
" Medium	.00120	.00067
" soft	.00110	.00061
Tin	.00210	.00117
Zinc, rolled	.00311	.00173
STONE AND MASONRY		
Ashlar masonry	.00063	.00035
Brick masonry	.00055	.00031
Cement, Portland	.00107	.00059
Concrete	.00143	.00079
" masonry	.00120	.00067
Granite	.00084	.00047
Limestone	.00080	.00044
Marble	.00100	.00056
Plaster	.00166	.00092
Rubble masonry	.00063	.00035
Sandstone	.00110	.00061
Slate	.00104	.00058

STANDARD GAGES

The practical metallurgist and engineer is very often confused with the various gages now in use. Table No. II is introduced, which shows the gage number and the thickness, in decimals of an inch, of the several gages now in common use. For example, No. 2 gage in the Birmingham wire, or B. W. G. gage, is .284 inches in thickness in plates, or diameter in wire. No. 2 gage in American wire, or Browne and Sharpe, is .257627 inches in thickness, or diameter. The table referred to above will enable one to determine the thickness or diameter of any wire when the gage number and particular gage are known. The following example will illustrate the use of this table.

What is the diameter of a No. 12 gage wire in American wire, or Browne and Sharpe gage? The number "12," showing the gage number, is found in the first column; going directly across the table to the right opposite the figure "12," under the column headed "American Wire, or Browne and Sharpe," is the figure .080808, which represents the diameter of the wire in inches.

TABLE II
STANDARD GAGES

Comparative Table

Gage Number	Thickness in Decimals of an Inch					
	Birmingham Wire (B.W.G.), also known as Stubs Iron Wire	American Wire or Browne & Sharpe	American Steel & Wire Company, formerly Washburn & Moen	Trenton Iron Company	British Imperial Standard Wire (S.W.G.)	Standard Birmingham Sheet and Hoop (B.G.)
0000000	....	.....	.4900	....	.500	.....
000000	....	.580000	.4615	....	.464	.....
00000	....	.516500	.4305	.450	.432	.....
0000	.454	.460000	.3938	.400	.400	.....
000	.425	.409642	.3625	.360	.372	.5000
00	.380	.364796	.3310	.330	.348	.4452
0	.340	.324861	.3065	.305	.324	.3964
1	.300	.289297	.2830	.285	.300	.3532
2	.284	.257627	.2625	.265	.276	.3147
3	.259	.229423	.2437	.245	.252	.2804
4	.238	.204307	.2253	.225	.232	.2500
5	.220	.181940	.2070	.205	.212	.2225
6	.203	.162023	.1920	.190	.192	.1981
7	.180	.144285	.1770	.175	.176	.1764
8	.165	.128490	.1620	.160	.160	.1570
9	.148	.114423	.1483	.145	.144	.1398
10	.134	.101897	.1350	.130	.128	.1250
11	.120	.090742	.1205	.1175	.116	.1113
12	.109	.080808	.1055	.105	.104	.0991
13	.095	.071962	.0915	.0925	.092	.0882
14	.083	.064084	.0800	.0806	.080	.0785
15	.072	.057068	.0720	.070	.072	.0699
16	.065	.050821	.0625	.061	.064	.0625
17	.058	.045257	.0540	.0525	.056	.0556
18	.049	.040303	.0475	.045	.048	.0495
19	.042	.035890	.0410	.040	.040	.0440
20	.035	.031961	.0348	.035	.036	.0392
21	.032	.028462	.03175	.031	.032	.0349
22	.028	.025346	.0286	.028	.028	.03125

STANDARD GAGES (*Continued*)

Comparative Table

Gage Number	Thickness in Decimals of an Inch					
	Birmingham Wire (B.W.G.), also known as Stubs Iron Wire	American Wire or Browne & Sharpe	American Steel & Wire Company, formerly Washburn & Moen	Trenton Iron Company	British Imperial Standard Wire (S.W.G.)	Standard Birmingham Sheet and Hoop (B.G.)
23	.025	.022572	.0258	.025	.024	.02782
24	.022	.020101	.0230	.0225	.022	.02476
25	.020	.017900	.0204	.020	.020	.02204
26	.018	.015941	.0181	.018	.018	.01961
27	.016	.014195	.0173	.017	.0164	.01745
28	.014	.012641	.0162	.016	.0148	.015625
29	.013	.011257	.0150	.015	.0136	.0139
30	.012	.010025	.0140	.014	.0124	.0123
31	.010	.008928	.0132	.013	.0116	.0110
32	.009	.007950	.0128	.012	.0108	.0098
33	.008	.007080	.0118	.011	.0100	.0087
34	.007	.006305	.0104	.010	.0092	.0077
35	.005	.005615	.0095	.0095	.0084	.0069
36	.004	.005000	.0090	.009	.0076	.0061
37	....	.004453	.0085	.0085	.0068	.0054
38	....	.003965	.0080	.008	.0060	.0048
39	....	.003531	.0075	.0075	.0052	.....
40	....	.003144	.0070	.007	.0048	.....

It is often convenient in the calibration of thermometers and thermocouples to have available certain definite points which can be used for calibration purposes. Table No. III gives the boiling and melting at normal atmospheric pressure for several substances which are readily obtainable, and which can be used for the purpose indicated.

TABLE III

STANDARD POINTS FOR THE CALIBRATION OF THERMOMETERS

Substance	Point	Atmosphere	Crucible	Temperatures °F.
Water	Boiling, 760 mm pressure	Air	.....	212.00
Napthalene	" " " "	"	.....	424.40
Benzophenone	" " " "	....	.....	582.53
Cadmium	Melting or solidify	Air	Graphite	609.44
Zinc	" " "	"	"	786.74
Sulphur	Boiling, 760 mm pressure	....	.....	832.01
Antimony	Melting or solidify	CO_2	Graphite	1165.64
Aluminum	Solidification	"	"	1217.30
Silver	Melting or solidify	"	"	1760.00
Gold	" " "	"	"	1944.32
Copper	" " "	"	"	1980.68
Li_2SiO_3	Melting	Air	Platinum	2193.80
Diopside, pure	"	"	"	2536.16
Nickel	Melting or solidify	H & N	Magnesia and Mag'a aluminate	2646.10
Cobalt	" " "	"	Magnesia	2713.64
Palladium	" " "	Air	"	2820.56
Platinum	Melting	"	.....	3185.60

TABLE IV

MELTING POINTS OF FIRE BRICK

The following table gives the melting point and softening point of certain refractory brick. This table should be found very useful in the design and construction of various types of furnaces.

SUBSTANCE	TEMPERATURE
Alumina	2100°, softens 1970° C.
Alundum	2050° C.
Bauxite	1820° C.
Bauxite brick	1620-1785° C.
Bone-ash cupel	1865° C.
Carborundum	Decomposes at 2220° with fusing.
Chromite	2050° C.
Clay brick, 1st class	1555-1740° C.
Clay brick, 2nd class	1400-1650° C.
Diatom nonpareil brick	900° C.
Dinas silica	1680° C.
Kaolinite (pure)	1740° C.
Lime (CaO)	Softens about 2040° C.
Magnesia	2720° C, softens about 2500° C.
Magnesite brick	2165° C, softens about 2000° C.
Silica	1700-1705° C.
Silicon carbide	2700° + C.

TABLE V

SPECIFIC GRAVITIES AND WEIGHTS

The following table gives the specific gravity and weight per cubic foot of a number of common substances which are in daily use by the practical metallurgist. These data are exceedingly useful in computing the weight of a given substance when the volume which it occupies is known. They are also very useful in comparing the weight per unit volume of different substances.

Substance	Specific Gravity	Weight, Pounds per cu. ft.
Metals, Alloys, Ores		
Aluminum, cast-hammered	2.55–2.75	165
" bronze	7.7	481
Antimony	6.62–6.72	416
Arsenic	5.73	358
Bismuth	9.70–9.78	608
Brass, cast-rolled	8.4–8.7	534
Bronze, 7.9 to 14% Sn	7.4–8.9	509
Chromium	6.80–6.92	428
Cobalt	8.72–8.95	552
Copper, cast-rolled	8.8–9.0	556
" ore, pyrites	4.1–4.3	262
Gold, cast-hammered	19.25–19.35	1205
Iron, cast, pig	7.2	450
" wrought	7.6–7.9	485
" steel	7.8–7.9	490
" spiegel-eisen	7.5	468
" ferro-silicon	6.7–7.3	437
" ore, hematite	5.2	325
" " " in bank	.....	160–180
" ore, hematite, loose	.....	130–160
Iron ore, limonite	3.6–4.0	237
Iron ore, magnetite	4.9–5.2	315
Iron slag	2.5–3.0	172
Lead	11.28–11.35	706
" ore, galena	7.3–7.6	465
Magnesium	1.74	109
Manganese	7.20–7.42	456
" ore, pyrolusite	3.7–4.6	259

SPECIFIC GRAVITIES AND WEIGHTS—(*Continued*)

Substance	Specific Gravity	Weight, Pounds per cu. ft.
Mercury	13.59	848
Molybdenum	9.01	562
Nickel	8.57–8.90	545
" monel metal	8.8–9.0	556
Platinum, cast-hammered	21.1–21.5	1330
Silver, cast-hammered	10.4–10.6	656
Tin, cast hammered	7.2–7.5	459
" babbit metal	7.1	443
" ore, cassiterite	6.4–7.0	418
Tungsten	18.7–19.1	1180
Vanadium	5.5–5.7	350
Zinc, cast-rolled	6.9–7.2	440
" ore, blende	3.9–4.2	253
Various Solids		
Carbon, amorphous, graphitic	1.88–2.25	129
Cork	0.24	15
Ebony	1.22	76
Fats	0.92–0.94	58
Glass, common, plate	2.40–2.72	160
" crystal	2.90–3.00	184
" flint	3.15–3.90	220
Phosphorus, white	1.83	114
Porcelain, china	2.30–2.50	150
Resins, Rosin, Amber	1.07	67
Rubber, caoutchouc	0.93	58
Silicon	2.49	155
Sulphur, amorphous	2.05	128
Wax	0.95–0.98	60
Various Liquids		
Alcohol, 100%	0.79	49
Acids, muriatic 40%	1.20	75
" nitric 91%	1.50	94
" sulphuric 87%	1.80	112
Lye, soda 66%	1.70	106
Oils, vegetable	0.91–0.94	58
" minerals, lubricants	0.90–0.93	57
Petroleum	0.88	55
Gasoline	0.66–0.69	42

SPECIFIC GRAVITIES AND WEIGHTS—(*Continued*)

Substance	Specific Gravity	Weight, Pounds per cu. ft.
Water, 4° C, max. density	1.0	62.428
" 100° C	0.9584	59.830
" ice	0.88–0.92	56
" snow, fresh fallen	.125	8
" sea water	1.02–1.03	64
Gases, Air = 1		
Air, 0° C, 760 mm	1.0	.08071
Ammonia	0.5920	.0478
Carbon dioxide	1.5291	.1234
Carbon monoxide	0.9673	.0781
Gas, illuminating	0.35–0.45	.028–.036
" natural	0.47–0.48	.038–.039
Hydrogen	0.0693	.00559
Nitrogen	0.9714	.0784
Oxygen	1.1056	.0892
Minerals		
Asbestos	2.1–2.8	153
Barytes	4.50	281
Basalt	2.7–3.2	184
Bauxite	2.55	159
Borax	1.7–1.8	109
Chalk	1.8–2.6	137
Clay, marl	1.8–2.6	137
Dolomite	2.9	181
Feldspar, orthoclase	2.5–2.6	159
Gneiss, serpentine	2.4–2.7	159
Granite, syenite	2.5–3.1	175
Greenstone, trap	2.8–3.2	187
Gypsum, alabaster	2.3–2.8	159
Hornblende	3.0	187
Limestone, marble	2.5–2.8	165
Magnesite	3.0	187
Phosphate rock, apatite	3.2	200
Porphyry	2.6–2.9	172
Pumice, natural	0.37–0.90	40
Quartz, flint	2.5–2.8	165
Sandstone, bluestone	2.2–2.5	147

SPECIFIC GRAVITIES AND WEIGHTS—(*Continued*)

Substance	Specific Gravity	Weight, Pounds per cu. ft.
Shale, slate	2.7–2.9	175
Soapstone, talc	2.6–2.8	169
Bituminous Substances		
Asphaltum	1.1–1.5	81
Coal, anthracite	1.4–1.7	97
" bituminous	1.2–1.5	84
" lignite	1.1–1.4	78
" peat, turf, dry	0.65–0.85	47
" charcoal, pine	0.28–0.44	23
" " oak	0.47–0.57	33
" coke	1.0–1.4	75
Graphite	1.9–2.3	131
Paraffine	0.87–0.91	56
Petroleum, crude	0.88	55
" refined	0.79–0.82	50
" benzine	0.73–0.75	46
" gasolene	0.66–0.69	42
Pitch	1.07–1.15	69
Tar, bituminous	1.20	75
Coal and Coke, Piled		
Coal, anthracite	.....	47–58
" bituminous, lignite	.....	40–54
" peat, turf	.....	20–26
" charcoal	.....	10–14
" coke	.....	23–32
Brick Masonry		
Pressed brick	2.2–2.3	140
Common brick	1.8–2.0	120
Soft brick	1.5–1.7	100
Concrete Masonry		
Cement, stone, sand	2.2–2.4	144
" slag, etc	1.9–2.3	130
" cinder, etc	1.5–1.7	100

SPECIFIC GRAVITIES AND WEIGHTS—(*Continued*)

Substance	Specific Gravity	Weight, Pounds per cu. ft.
Various Building Material		
Ashes, cinders	.....	40–45
Cement, Portland, loose	.....	90
" " set	2.7–3.2	183
Lime, gypsum, loose	.....	65–75
Mortar, set	1.4–1.9	103
Slags, bank slag	.....	67–72
" " screenings	.....	98–117
" machine slag	.....	96
" slag sand	.....	49–55
Earth, Etc., Excavated		
Clay, dry	.....	63
" damp, plastic	.....	110
Clay and gravel, dry	.....	100
Earth, dry, loose	.....	76
" " packed	.....	95
" moist, loose	.....	78
" " packed	.....	96
" mud, flowing	.....	108
" " packed	.....	115
Riprap, limestone	.....	80–85
" sandstone	.....	90
" shale	.....	105
Sand, gravel, dry, loose	.....	90–105
" " " packed	.....	100–120
" " " wet	.....	118–120

SQUARE AND ROUND BARS

The following table (Table VI) gives the weight per foot, and also the area in square inches, for square and round steel bars of different dimensions, from 1/16 inch diameter to 9 inches.

If it is desired to obtain the weight of a plate of any given width, it is only necessary to find the weight per foot of a square bar having the thickness of the plate in question and then multiply this weight by the number of times the thickness is contained in the width. Suppose, for example, it is desired to obtain the weight per foot of a plate ½ inch thick and 24 inches in width. Referring to the table, a square bar ½ inch on the side weighs .85 pound per foot. A plate ½ inch thick and 24 inches wide will weigh, therefore, .85 x (24 ÷ ½) = .85 x 48.

TABLE VI

SQUARE AND ROUND BARS

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
0				
1/16	.013	.010	.0039	.0031
1/8	.053	.042	.0156	.0123
3/16	.120	.094	.0352	.0276
1/4	.213	.167	.0625	.0491
5/16	.332	.261	.0977	.0767
3/8	.478	.376	.1406	.1105
7/16	.651	.511	.1914	.1503
1/2	.850	.668	.2500	.1963
9/16	1.076	.845	.3164	.2485
5/8	1.328	1.043	.3906	.3068
11/16	1.607	1.262	.4727	.3712
3/4	1.913	1.502	.5625	.4418
13/16	2.245	1.763	.6602	.5185
7/8	2.603	2.044	.7656	.6013
15/16	2.988	2.347	.8789	.6903
1	3.400	2.670	1.0000	.7854
1/16	3.838	3.015	1.1289	.8866
1/8	4.303	3.380	1.2656	.9940
3/16	4.795	3.766	1.4102	1.1075
1/4	5.313	4.172	1.5625	1.2272
5/16	5.857	4.600	1.7227	1.3530
3/8	6.428	5.049	1.8906	1.4849
7/16	7.026	5.518	2.0664	1.6230
1/2	7.650	6.008	2.2500	1.7671
9/16	8.301	6.519	2.4414	1.9175
5/8	8.978	7.051	2.6406	2.0739
11/16	9.682	7.604	2.8477	2.2365
3/4	10.413	8.178	3.0625	2.4053
13/16	11.170	8.773	3.2852	2.5802

SQUARE AND ROUND BARS (*Continued*)

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
1 7/8	11.953	9.388	3.5156	2.7612
15/16	12.763	10.024	3.7539	2.9483
2	13.600	10.681	4.0000	3.1416
1/16	14.463	11.359	4.2539	3.3410
1/8	15.353	12.058	4.5156	3.5466
3/16	16.270	12.778	4.7852	3.7583
1/4	17.213	13.519	5.0625	3.9761
5/16	18.182	14.280	5.3477	4.2000
3/8	19.178	15.062	5.6406	4.4301
7/16	20.201	15.866	5.9414	4.6664
1/2	21.250	16.690	6.2500	4.9087
9/16	22.326	17.534	6.5664	5.1572
5/8	23.428	18.400	6.8906	5.4119
11/16	24.557	19.287	7.2227	5.6727
3/4	25.713	20.195	7.5625	5.9396
13/16	26.895	21.123	7.9102	6.2126
7/8	28.103	22.072	8.2656	6.4918
15/16	29.338	23.042	8.6289	6.7771
3	30.600	24.033	9.0000	7.0686
1/16	31.89	25.05	9.379	7.366
1/8	33.20	26.08	9.766	7.670
3/16	34.54	27.13	10.160	7.980
1/4	35.91	28.21	10.563	8.296
5/16	37.31	29.30	10.973	8.618
3/8	38.73	30.42	11.391	8.946
7/16	40.18	31.55	11.816	9.281
1/2	41.65	32.71	12.250	9.621
9/16	43.15	33.89	12.691	9.968
5/8	44.68	35.09	13.141	10.321
11/16	46.23	36.31	13.598	10.680

SQUARE AND ROUND BARS (*Continued*)

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
3 3/4	47.81	37.55	14.063	11.045
13/16	49.42	38.81	14.535	11.416
7/8	51.05	40.10	15.016	11.793
15/16	52.71	41.40	15.504	12.177
4	54.40	42.73	16.000	12.566
1/16	56.11	44.07	16.504	12.962
1/8	57.85	45.44	17.016	13.364
3/16	59.62	46.83	17.535	13.772
1/4	61.41	48.23	18.063	14.186
5/16	63.23	49.66	18.598	14.607
3/8	65.08	51.11	19.141	15.033
7/16	66.95	52.58	19.691	15.466
1/2	68.85	54.07	20.250	15.904
9/16	70.78	55.59	20.816	16.349
5/8	72.73	57.12	21.391	16.800
11/16	74.71	58.67	21.973	17.257
3/4	76.71	60.25	22.563	17.721
13/16	78.74	61.85	23.160	18.190
7/8	80.80	63.46	23.766	18.665
15/16	82.89	65.10	24.379	19.147
5	85.00	66.76	25.000	19.635
1/16	87.14	68.44	25.629	20.129
1/8	89.30	70.14	26.266	20.629
3/16	91.49	71.86	26.910	21.135
1/4	93.71	73.60	27.563	21.648
5/16	95.96	75.36	28.223	22.166
3/8	98.23	77.15	28.891	22.691
7/16	100.53	78.95	29.566	23.221
1/2	102.85	80.78	30.250	23.758
9/16	105.20	82.62	30.941	24.301

SQUARE AND ROUND BARS (*Continued*)

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
5 5/8	107.58	84.49	31.641	24.850
11/16	109.98	86.38	32.348	25.406
3/4	112.41	88.29	33.063	25.967
13/16	114.87	90.22	33.785	26.535
7/8	117.35	92.17	34.516	27.109
15/16	119.86	94.14	35.254	27.688
6	122.40	96.13	36.000	28.274
1/16	124.96	98.15	36.754	28.866
1/8	127.55	100.18	37.516	29.465
3/16	130.17	102.23	38.285	30.069
1/4	132.81	104.31	39.063	30.680
5/16	135.48	106.41	39.848	31.296
3/8	138.18	108.53	40.641	31.919
7/16	140.90	110.66	41.441	32.548
1/2	143.65	112.82	42.250	33.183
9/16	146.43	115.00	43.066	33.824
5/8	149.23	117.20	43.891	34.472
11/16	152.06	119.43	44.723	35.125
3/4	154.91	121.67	45.563	35.785
13/16	157.79	123.93	46.410	36.450
7/8	160.70	126.22	47.266	37.122
15/16	163.64	128.52	48.129	37.800
7	166.60	130.85	49.000	38.485
1/16	169.59	133.19	49.879	39.175
1/8	172.60	135.56	50.766	39.871
3/16	175.64	137.95	51.660	40.574
1/4	178.71	140.36	52.563	41.282
5/16	181.81	142.79	53.473	41.997
3/8	184.93	145.24	54.391	42.718
7/16	188.07	147.71	55.316	43.445

SQUARE AND ROUND BARS (*Continued*)

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
7 1/2	191.25	150.21	56.250	44.179
9/16	194.45	152.72	57.191	44.918
5/8	197.68	155.26	58.141	45.664
11/16	200.93	157.81	59.098	46.415
3/4	204.21	160.39	60.063	47.173
13/16	207.52	162.99	61.035	47.937
7/8	210.85	165.60	62.016	48.707
15/16	214.21	168.24	63.004	49.483
8	217.60	170.90	64.000	50.265
1/16	221.01	173.58	65.004	51.054
1/8	224.45	176.29	66.016	51.849
3/16	227.92	179.01	67.035	52.649
1/4	231.41	181.75	68.063	53.456
5/16	234.93	184.52	69.098	54.269
3/8	238.48	187.30	70.141	55.088
7/16	242.05	190.11	71.191	55.914
1/2	245.65	192.93	72.250	56.745
9/16	249.28	195.78	73.316	57.583
5/8	252.93	198.65	74.391	58.426
11/16	256.61	201.54	75.473	59.276
3/4	260.31	204.45	76.563	60.132
13/16	264.04	207.38	77.660	60.994
7/8	267.80	210.33	78.766	61.863
15/16	271.59	213.31	79.879	62.737
9	275.40	216.30	81.000	63.617
1/16	279.24	219.31	82.129	64.504
1/8	283.10	222.35	83.266	65.397
3/16	286.99	225.41	84.410	66.296
1/4	290.91	228.48	85.563	67.201
5/16	294.86	231.58	86.723	68.112
3/8	298.83	234.70	87.891	69.029
7/16	302.83	237.84	89.066	69.953

SQUARE AND ROUND BARS (*Continued*)

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
9 1/2	306.85	241.00	90.250	70.882
9/16	310.90	244.18	91.441	71.818
5/8	314.98	247.38	92.641	72.760
11/16	319.08	250.61	93.848	73.708
3/4	323.21	253.85	95.063	74.662
13/16	327.37	257.12	96.285	75.622
7/8	331.55	260.40	97.516	76.589
15/16	335.76	263.71	98.754	77.561
10	340.00	267.04	100.000	78.540
1/16	344.26	270.38	101.254	79.525
1/8	348.55	273.75	102.516	80.516
3/16	352.87	277.14	103.785	81.513
1/4	357.21	280.55	105.063	82.516
5/16	361.58	283.99	106.348	83.525
3/8	365.98	287.44	107.641	84.541
7/16	370.40	290.91	108.941	85.563
1/2	374.85	294.41	110.250	86.590
9/16	379.33	297.92	111.566	87.624
5/8	383.83	301.46	112.891	88.664
11/16	388.36	305.02	114.223	89.710
3/4	392.91	308.59	115.563	90.763
13/16	397.49	312.19	116.910	91.821
7/8	402.10	315.81	118.266	92.886
15/16	406.74	319.45	119.629	93.957
11	411.40	323.11	121.000	95.033
1/16	416.09	326.80	122.379	96.116
1/8	420.80	330.50	123.766	97.205
3/16	425.54	334.22	125.160	98.301
1/4	430.31	337.97	126.563	99.402
5/16	435.11	341.73	127.973	100.510
3/8	439.93	345.52	129.391	101.623
7/16	444.78	349.33	130.816	102.743

SQUARE AND ROUND BARS (*Continued*)

Weights and Areas

Size, Inches	Weight, Lbs. per Foot		Area, Square Inches	
	Square	Round	Square	Round
11 1/2	449.65	353.16	132.250	103.869
9/16	454.55	357.00	133.691	105.001
5/8	459.48	360.87	135.141	106.139
11/16	464.43	364.76	136.598	107.284
3/4	469.41	368.68	138.063	108.434
13/16	474.42	372.61	139.535	109.591
7/8	479.45	376.56	141.016	110.754
15/16	484.51	380.54	142.504	111.923
12	489.60	384.53	144.000	113.098

WEIGHT OF FLAT BAR STEEL

PER FOOT

	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	2	2¼	2½	2¾	3
1/16	.1060	.1381	.1594	.1859	.212	.2391	.2656	.292	.319	.346	.372	.425	.478	.531	.584	.638
⅛	.2125	.2656	.3188	.372	.425	.4782	.5312	.585	.638	.692	.744	.85	.96	1.06	1.17	1.28
3/16	.319	.399	.478	.558	.638	717	.797	.875	.957	1.04	1.15	1.28	1.44	1.59	1.75	1.91
¼	.425	.531	.636	.743	.85	.957	1.06	1.17	1.28	1.38	1.49	1.70	1.92	2.12	2.34	2.55
5/16	.531	.664	.797	.929	1.06	1.20	1.33	1.46	1.59	1.73	1.86	2.12	2.39	2.65	2.92	3.19
⅜	.638	.797	.957	1.116	1.28	1.43	1.59	1.76	1.92	2.08	2.23	2.55	2.87	3.19	3.51	3.83
7/16	.744	.929	1.116	1.302	1.49	1.68	1.86	2.05	2.23	2.42	2.60	2.98	3.35	3.72	4.09	4.46
½	.850	1.06	1.275	1.487	1.70	1.92	2.12	2.34	2.55	2.72	2.98	3.40	3.83	4.25	4.67	5.10
9/16	.957	1.20	1.434	1.674	1.92	2.15	2.39	2.63	2.87	3.11	3.35	3.83	4.30	4.78	5.26	5.74
⅝	1.06	1.33	1.594	1.859	2.12	2.39	2.65	2.92	3.19	3.46	3.72	4.25	4.78	5.31	5.84	6.38
11/16	1.17	1.46	1.753	2.045	2.34	2.63	2.92	3.22	3.51	3.80	4.09	4.67	5.26	5.84	6.43	7.02
¾	1.28	1.60	1.913	2.232	2.55	2.87	3.19	3.51	3.83	4.15	4.47	5.10	5.75	6.38	7.02	7.65
13/16	1.38	1.73	2.072	2.417	2.76	3.11	3.45	3.80	4.14	4.49	4.84	5.53	6.21	6.90	7.60	8.29
⅞	1.49	1.86	2.232	2.604	2.98	3.35	3.72	4.09	4.47	4.84	5.20	5.95	6.69	7.44	8.18	8.93
15/16	1.60	1.99	2.391	2.789	3.19	3.59	3.99	4.39	4.78	5.18	5.58	6.38	7.18	7.97	8.77	9.57
1	1.70	2.13	2.55	2.98	3.40	3.83	4.25	4.68	5.10	5.53	5.95	6.80	7.65	8.50	9.35	10.20
1 1/8	1.91	2.39	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.22	6.70	7.65	8.61	9.57	10.52	11.48
1 ¼	2.12	2.66	3.19	3.72	4.25	4.79	5.31	5.85	6.38	6.91	7.44	8.50	9.57	10.63	11.69	12.75
1 3/8	2.34	2.92	3.51	4.09	4.67	5.26	5.84	6.43	7.02	7.60	8.18	9.35	10.52	11.69	12.85	14.03
1 ½	2.55	3.19	3.83	4.47	5.10	5.74	6.38	7.02	7.65	8.29	8.93	10.20	11.48	12.75	14.03	15.30
1 5/8	2.76	3.45	4.15	4.84	5.52	6.22	6.90	7.60	8.29	8.98	9.67	11.05	12.43	13.81	15.19	16.58
1 ¾	2.98	3.72	4.47	5.21	5.95	6.70	7.44	8.19	8.93	9.67	10.42	11.90	13.40	14.88	16.37	17.85
1 7/8	3.19	3.99	4.79	5.58	6.38	7.17	7.97	8.77	9.57	10.36	11.15	12.75	14.34	15.94	17.53	19.13
2	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	10.20	11.05	11.90	13.60	15.30	17.00	18.70	20.40

WEIGHT OF FLAT BAR STEEL

PER FOOT—(*Continued*)

	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7
1/16	.691	.741	.80	.85	.90	.96	1.01	1.06	1.12	1.17	1.22	1.27	1.33	1.38	1.43	1.49
1/8	1.38	1.49	1.59	1.70	1.81	1.91	2.02	2.13	2.23	2.34	2.44	2.55	2.66	2.76	2.87	2.97
3/16	2.07	2.23	2.39	2.55	2.71	2.87	3.03	3.19	3.35	3.51	3.67	3.83	3.99	4.14	4.30	4.46
1/4	2.76	2.98	3.19	3.40	3.61	3.83	4.04	4.25	4.46	4.67	4.89	5.10	5.31	5.53	5.74	5.95
5/16	3.45	3.72	3.99	4.25	4.52	4.78	5.05	5.31	5.58	5.84	6.11	6.38	6.64	6.90	7.17	7.44
3/8	4.15	4.47	4.78	5.10	5.42	5.74	6.06	6.38	6.69	7.02	7.34	7.65	7.97	8.29	8.61	8.93
7/16	4.83	5.20	5.58	5.95	6.32	6.70	7.07	7.44	7.81	8.18	8.56	8.93	9.29	9.67	10.04	10.41
1/2	5.53	5.95	6.38	6.80	7.22	7.65	8.08	8.50	8.93	9.35	9.77	10.20	10.63	11.05	11.48	11.90
9/16	6.22	6.70	7.17	7.65	8.13	8.61	9.09	9.57	10.04	10.52	11.00	11.48	11.95	12.43	12.91	13.39
5/8	6.91	7.44	7.97	8.50	9.03	9.57	10.10	10.63	11.16	11.69	12.22	12.75	13.28	13.81	14.34	14.87
11/16	7.60	8.18	8.76	9.35	9.93	10.52	11.11	11.69	12.27	12.85	13.44	14.03	14.61	15.20	15.78	16.36
3/4	8.29	8.93	9.57	10.20	10.84	11.48	12.12	12.75	13.39	14.03	14.67	15.30	15.94	16.58	17.22	17.85
13/16	8.98	9.67	10.36	11.05	11.74	12.43	13.12	13.81	14.50	15.19	15.88	16.58	17.27	17.95	18.65	19.34
7/8	9.67	10.41	11.16	11.90	12.65	13.39	14.13	14.87	15.62	16.36	17.10	17.85	18.60	19.34	20.08	20.83
15/16	10.36	11.16	11.95	12.75	13.55	14.34	15.14	15.94	16.74	17.53	18.83	19.13	19.92	20.72	21.51	22.32
1	11.05	11.90	12.75	13.60	14.45	15.30	16.15	17.00	17.85	18.70	19.55	20.40	21.25	22.10	22.95	23.80
1 1/8	12.43	13.39	14.34	15.30	16.26	17.22	18.17	19.13	20.08	21.04	21.99	22.95	23.91	24.87	25.82	26.78
1 1/4	13.81	14.87	15.94	17.00	18.06	19.13	20.19	21.25	22.32	23.38	24.44	25.50	26.56	27.62	28.69	29.75
1 3/8	15.20	16.36	17.53	18.70	19.87	21.04	22.21	23.38	24.54	25.71	26.88	28.05	29.22	30.39	31.56	32.72
1 1/2	16.58	17.85	19.13	20.40	21.68	22.95	24.23	25.50	26.78	28.05	29.33	30.60	31.88	33.15	34.43	35.70
1 5/8	17.96	19.34	20.72	22.10	23.48	24.87	26.25	27.63	29.01	30.39	31.77	33.15	34.53	35.91	37.99	38.67
1 3/4	19.34	20.83	22.32	23.80	25.29	26.78	28.27	29.75	31.24	32.73	34.22	35.70	37.19	38.68	40.17	41.65
1 7/8	20.72	22.31	23.91	25.50	27.10	28.69	30.28	31.87	33.47	35.06	36.65	38.25	38.85	41.44	43.03	44.63
2	22.10	23.80	25.50	27.20	28.90	30.60	32.30	34.00	35.70	37.40	39.10	40.80	42.50	44.20	45.90	47.60

In estimating the weight for High Speed Steel increase the weights as given above by 10%

TEMPERATURE CONVERSION TABLES

ALBERT SAUVEUR

—459.4 TO 0

C		F
—273	—459.4	
—268	—450	
—262	—440	
—257	—430	
—251	—420	
—246	—410	
—240	—400	
—234	—390	
—229	—380	
—223	—370	
—218	—360	
—212	—350	
—207	—340	
—201	—330	
—196	—320	
—190	—310	
—184	—300	
—179	—290	
—173	—280	
—169	—273	—459.4
—168	—270	—454
—162	—260	—436
—157	—250	—418
—151	—240	—400
—146	—230	—382
—140	—220	—364
—134	—210	—346
—129	—200	—328
—123	—190	—310
—118	—180	—292
—112	—170	—274
—107	—160	—256
—101	—150	—238
— 96	—140	—220
— 90	—130	—202
— 84	—120	—184
— 79	—110	—166
— 73	—100	—148
— 68	— 90	—130
— 62	— 80	—112
— 57	— 70	— 94
— 51	— 60	— 76
— 46	— 50	— 58
— 40	— 40	— 40
— 34	— 30	— 22
— 29	— 20	— 4
— 23	— 10	14
— 17.7	0	32

0 TO 100

C		F	C		F
—17.7	0	32	9.9	50	122 0
—17.2	1	33.8	10.4	51	123 8
—16.6	2	35 6	11.1	52	125 6
—16.1	3	37.4	11.5	53	127 4
—15.5	4	39.2	12.1	54	129 2
—15.0	5	41.0	12.6	55	131 0
—14.4	6	42.8	13.2	56	132 8
—13 9	7	44.6	13.7	57	134 6
—13 3	8	46.4	14.3	58	136.4
—12.7	9	48.2	14.8	59	138 2
—12 2	10	50 0	15.6	60	140 0
—11.6	11	51.8	16.1	61	141 8
—11 1	12	53.6	16 6	62	143 6
—10.5	13	55.4	17.1	63	145.4
—10.0	14	57 2	17 7	64	147 2
— 9 4	15	59 0	18.2	65	149 0
— 8 8	16	61.8	18 8	66	150 8
— 8 3	17	63.6	19.3	67	152.6
— 7.7	18	65.4	19.9	68	154.4
— 7 2	19	67 2	20.4	69	156 2
— 6.6	20	68.0	21.0	70	158.0
— 6.1	21	69.8	21.5	71	159.8
— 5.5	22	71.6	22.2	72	161 6
— 5.0	23	73.4	22.7	73	163.4
— 4 4	24	75 2	23.3	74	165 2
— 3 9	25	77.0	23.8	75	167.0
— 3.3	26	78.8	24.4	76	168 8
— 2 8	27	80 6	25 0	77	170 6
— 2 2	28	82.4	25.5	78	172 4
— 1 6	29	84 2	26.2	79	174 2
— 1.1	30	86.0	26.8	80	176 0
— .6	31	87.8	27.3	81	177.8
0	32	89.6	27 7	82	179.6
.5	33	91.4	28 2	83	181 4
1.1	34	93.2	28 8	84	183.2
1 6	35	95.0	29 3	85	185.0
2.2	36	96 8	29.9	86	186 8
2.7	37	98.6	30 4	87	188.6
3 3	38	100 4	31.0	88	190.4
3.8	39	102.2	31 5	89	192 2
4 4	40	104 0	32.1	90	194 0
4 9	41	105 8	32.6	91	195 8
5.5	42	107.6	33 3	92	197.6
6 0	43	109.4	33 8	93	199.4
6.6	44	111.2	34 4	94	201.2
7.1	45	113 0	34 9	95	203.0
7.7	46	114 8	35.5	96	204.8
8.2	47	116.6	36.1	97	206.6
8.8	48	118.4	36.6	98	208.4
9.3	49	120.2	37.1	99	210.2
			37.7	100	212.0

100 TO 1000

C		F	C		F
38	100	212	260	500	932
43	110	230	265	510	950
49	120	248	271	520	968
54	130	266	276	530	986
60	140	284	282	540	1004
65	150	302	288	550	1022
71	160	320	293	560	1040
76	170	338	299	570	1058
83	180	356	304	580	1076
88	190	374	310	590	1094
93	200	392	315	600	1112
99	210	410	321	610	1130
100	212	413	326	620	1148
104	220	428	332	630	1166
110	230	446	338	640	1184
115	240	464	343	650	1202
121	250	482	349	660	1220
127	260	500	354	670	1238
132	270	518	360	680	1256
138	280	536	365	690	1274
143	290	554	371	700	1292
149	300	572	376	710	1310
154	310	590	382	720	1328
160	320	608	387	730	1346
165	330	626	393	740	1364
171	340	644	399	750	1382
177	350	662	404	760	1400
182	360	680	410	770	1418
188	370	698	415	780	1436
193	380	716	421	790	1454
199	390	734	426	800	1472
204	400	752	432	810	1490
210	410	770	438	820	1508
215	420	788	443	830	1526
221	430	806	449	840	1544
226	440	824	454	850	1562
232	450	842	460	860	1580
238	460	860	465	870	1598
243	470	878	471	880	1616
249	480	896	476	890	1634
254	490	914	482	900	1652
			487	910	1670
			493	920	1688
			498	930	1706
			504	940	1724
			510	950	1742
			515	960	1760
			520	970	1778
			526	980	1796
			532	990	1814
			538	1000	1832

1000 TO 2000

C		F	C		F
538	1000	1832	815	1500	2732
543	1010	1850	820	1510	2750
549	1020	1868	827	1520	2768
554	1030	1886	831	1530	2786
560	1040	1904	838	1540	2804
565	1050	1922	842	1550	2822
571	1060	1940	849	1560	2840
576	1070	1958	853	1570	2858
582	1080	1976	860	1580	2876
587	1090	1994	864	1590	2894
593	1100	2012	871	1600	2912
598	1110	2030	876	1610	2930
604	1120	2048	882	1620	2948
609	1130	2066	887	1630	2966
615	1140	2084	893	1640	2984
620	1150	2102	898	1650	3002
626	1160	2120	904	1660	3020
631	1170	2138	909	1670	3038
637	1180	2156	915	1680	3056
642	1190	2174	920	1690	3074
648	1200	2192	926	1700	3092
653	1210	2210	931	1710	3110
659	1220	2228	937	1720	3128
664	1230	2246	942	1730	3146
670	1240	2264	948	1740	3164
675	1250	2282	953	1750	3182
681	1260	2300	959	1760	3200
686	1270	2318	964	1770	3218
692	1280	2336	970	1780	3236
697	1290	2354	975	1790	3254
704	1300	2372	981	1800	3272
708	1310	2390	986	1810	3290
715	1320	2408	992	1820	3308
719	1330	2426	997	1830	3326
726	1340	2444	1003	1840	3344
734	1350	2462	1008	1850	3362
737	1360	2480	1014	1860	3380
741	1370	2498	1019	1870	3398
748	1380	2516	1025	1880	3416
752	1390	2534	1030	1890	3434
760	1400	2552	1036	1900	3452
765	1410	2570	1041	1910	3470
771	1420	2588	1047	1920	3488
776	1430	2606	1052	1930	3506
782	1440	2624	1058	1940	3524
787	1450	2642	1063	1950	3542
793	1460	2660	1069	1960	3560
798	1470	2678	1074	1970	3578
804	1480	2696	1080	1980	3596
809	1490	2714	1085	1990	3614
			1093	2000	3632

2000 TO 3000

C		F	C		F
1093	2000	3632	1371	2500	4532
1098	2010	3650	1376	2510	4550
1104	2020	3668	1382	2520	4568
1109	2030	3686	1387	2530	4586
1115	2040	3704	1393	2540	4604
1120	2050	3722	1398	2550	4622
1126	2060	3740	1404	2560	4640
1131	2070	3758	1409	2570	4658
1137	2080	3776	1415	2580	4676
1142	2090	3794	1420	2590	4694
1149	2100	3812	1427	2600	4712
1154	2110	3830	1432	2610	4730
1160	2120	3848	1438	2620	4748
1165	2130	3866	1443	2630	4766
1171	2140	3884	1449	2640	4784
1176	2150	3902	1454	2650	4802
1182	2160	3920	1460	2660	4820
1187	2170	3938	1465	2670	4838
1193	2180	3956	1471	2680	4856
1198	2190	3974	1476	2690	4874
1204	2200	3992	1483	2700	4892
1209	2210	4010	1488	2710	4910
1215	2220	4028	1494	2720	4928
1220	2230	4046	1499	2730	4946
1226	2240	4064	1505	2740	4964
1231	2250	4082	1510	2750	4982
1237	2260	4100	1516	2760	5000
1242	2270	4118	1521	2770	5018
1248	2280	4136	1527	2780	5036
1253	2290	4154	1532	2790	5054
1259	2300	4172	1538	2800	5072
1264	2310	4190	1543	2810	5090
1270	2320	4208	1549	2820	5108
1275	2330	4226	1554	2830	5126
1281	2340	4244	1560	2840	5144
1286	2350	4262	1565	2850	5162
1292	2360	4280	1571	2860	5180
1297	2370	4298	1576	2870	5198
1303	2380	4316	1582	2880	5216
1308	2390	4334	1587	2890	5234
1315	2400	4352	1593	2900	5252
1320	2410	4370	1598	2910	5270
1326	2420	4388	1604	2920	5288
1331	2430	4406	1609	2930	5306
1337	2440	4424	1615	2940	5324
1342	2450	4442	1620	2950	5342
1348	2460	4460	1626	2960	5360
1353	2470	4478	1631	2970	5378
1359	2480	4496	1637	2980	5396
1364	2490	4514	1642	2990	5414
			1649	3000	5432

NOTE:—The numbers in BLACK FACE refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade degrees the equivalent temperature will be found in the left column, while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

To Reduce the Degrees of a Fahrenheit Thermometer to Those of Reaumer and the Centigrade, and Contrariwise

Fahrenheit to Reaumer.—If above the freezing point.—Subtract 32 from the number of degrees; multiply the remainder by 4, and divide the product by 9.

Thus, 212°—32°=180°, and 180°×4÷9=80°.

If below the freezing point.—Add 32 to the number of degrees; multiply the sum by 4, and divide the product by 9.

Thus, 40°+32°=72°, and 72°×4÷9=—32°.

Reaumer to Fahrenheit.—Multiply the number of degrees by 9, and divide the product by 4. Then when they are above the freezing point, add 32 to the quotient, and when they are below, subtract 32.

Thus, 80°×9÷4=180, and 180+32=212°.

" —32°×9÷4=72, and 72—32=40°.

Fahrenheit to Centigrade.—If above the freezing point.—Subtract 32 from the number of degrees; multiply the remainder by 5, and divide the product by 9.

Thus, 212°—32°×5÷9=180×5÷9=100°.

If below the freezing point.—Add 32 to the number of degrees; multiply the sum by 5, and divide the product by 9.

Thus, —40°+32×5÷9=72×5÷9=—40°.

Centigrade to Fahrenheit.—Multiply the number of degrees by 9, and divide the product by 5. Then, when they are above the freezing point, add 32 to the quotient, and when they are below, subtract 32.

Thus, 100°×9÷5=180, and 180+32=212°.

" —10°×9÷5=18, and 18—32=14°.

Reaumer to Centigrade.—Multiply by 5 and divide by 4—thus: 80°×5=400, and 400÷4=100.

Centigrade to Reaumer.—Multiply by 4 and divide by 5.

Thus 100°×4=400, and 400÷5=80°.

INCANDESCENT COLORS AND TEMPERATURES

Taylor & White's Table

	Fahr.	Cent.
Black Red	990	533
Dark Blood Red	1050	565
Dark Cherry Red	1175	634
Medium Cherry Red	1250	676
Full Cherry Red	1375	745
Light Cherry, Scaling	1550	843
Salmon	1650	899
Light Salmon	1725	940
Yellow	1825	995
Light Yellow	1975	1078
White	2220	1203

COLORS OF TEMPERING HEATS

Temperature held for 1 hour		Color of Oxides	Temperature held for 8 minutes	
370	188	Faint Yellow	460	238
390	199	Light Straw	510	265
410	210	Dark Straw	560	293
430	221	Brown	610	321
450	232	Purple	640	337
490	254	Dark Blue	660	349
510	265	Light Blue	710	376

USEFUL INFORMATION

A gallon of water weighs 8⅓ pounds and contains 231 cubic inches.

A cubic foot of fresh water weighs 62.4 pounds and contains 1728 cubic inches or 7.48 gallons.

The diameter of a circle equals the circumference divided by 3.1416.

The circumference of a circle equals diameter x 3.1416 or 3⅐.

The area of a circle equals the square of the diameter x .7854 or the square of the radius x 3.1416.

The side of a square in area to a given circle equals diameter x .8862.

Water pressure per square inch at different heads is equal to the product of the head in feet by .4331.

A liter equals .26418 gallons.

Doubling the diameter of a pipe multiplies its end area four times.

AVOIRDUPOIS OR COMMERCIAL WEIGHTS (ENGLISH)

28 pounds	=	1 quarter.		
4 quarters	=	1 hundredweight	=	112 lbs.
20 hundredweight	=	1 long ton	=	2240 lbs.

METRIC OR FRENCH LINEAL MEASURE

	Metres	Inches	Feet
Millemetre	.001	.03937	.00328
Centrimetre	.01	.3937	.03280
Decimetre	.1	3.937	.32807
Metre	1	39.3685	3.2807
Decametre	10		32.807
Hectometre	100		328.07
Kilometre	1000		3280.7
Myriametre	10000		32807

TABLE OF DECIMAL EQUIVALENTS

Of 4ths, 8ths, 16ths, 32nds and 64ths of an Inch for Use in Connection with Micrometer Calipers.

4ths.	8ths.
1/8	= .125
1/4	= .25
3/8	= .375
1/2	= .50
5/8	= .625
3/4	= .75
7/8	= .875

16ths.	
1/16	= .0625
3/16	= .1875
5/16	= .3125
7/16	= .4375
9/16	= .5625
11/16	= .6875
13/16	= .8125
15/16	= .9375

32nds.	
1/32	= .03125
3/32	= .09375
5/32	= .15625
7/32	= .21875
9/32	= .28125
11/32	= .34375
13/32	= .40625
15/32	= .46875
17/32	= .53125
19/32	= .59375
21/32	= .65625
23/32	= .71875
25/32	= .78125
27/32	= .84375
29/32	= .90625
31/32	= .96875

64ths.	
1/64	= .015625
3/64	= .046875
5/64	= .078125
7/64	= .109375
9/64	= .140625
11/64	= .171875
13/64	= .203125
15/64	= .234375
17/64	= .265625
19/64	= .296875
21/64	= .328125
23/64	= .359375
25/64	= .390625
27/64	= .421875
29/64	= .453125
31/64	= .484375
33/64	= .515625
35/64	= .546875
37/64	= .578125
39/64	= .609375
41/64	= .640625
43/64	= .671875
45/64	= .703125
47/64	= .734375
49/64	= .765625
51/64	= .796875
53/64	= .828125
55/64	= .859375
57/64	= .890625
59/64	= .921875
61/64	= .953125
63/64	= .984375

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